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ADMINISTRATIVE AND TECHNICAL ASPECTS OF SOURCE SAMPLING FOR PARTICULATES

PEDCO-Environmental Specialists, Incorporated

PREPARED FOR
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August 1974

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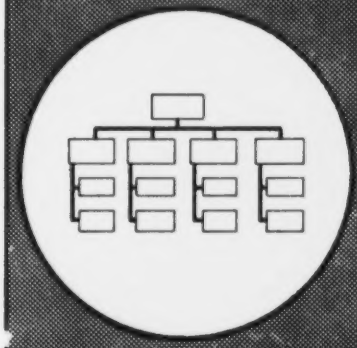

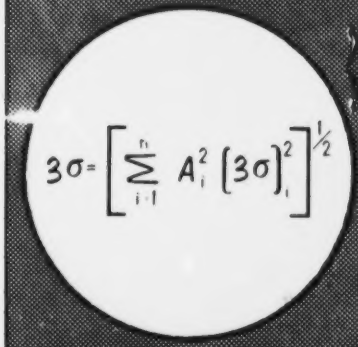

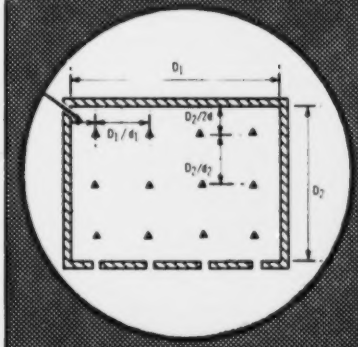

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The technical and administrative aspects of establishing and conducting a source-sampling program within an air pollution control agency are presented. Administrative aspects include legal aspects, organization, personnel and equipment needs, and costs. Technical aspects and a detailed explanation of conducting a source-sampling test for particulate matter are described. Sources of error and the magnitude of errors are included.

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Office of Air Quality Planning and Standards
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Mr. Gene W. Smith of the Office of Air and Waste Management, Environmental Protection Agency, was the project officer.

ABSTRACT

The technical and administrative aspects of establishing and conducting a source-sampling program within an air pollution control agency are presented. Administrative aspects include legal aspects, organization, personnel and equipment needs, and costs. Technical aspects and a detailed explanation of conducting a source-sampling test for particulate matter are described. Sources of error and the magnitude of errors are included.

Key words: air pollution, source sampling, particulate.

CONTENTS

		Page
List of Figures		vii
List of Tables		viii
Introduction		ix
1.	Source-Sampling Purposes	1-1
2.	Functions of the Source-Sampling Unit	2-1
	2.1 Specific Duties Assigned to the Source-Sampling Unit	2-1
3.	Regulations Required to Conduct Source Sampling	3-1
	3.1 Statutory Authorization to Establish Program	3-1
	3.1.1. State Programs	3-1
	3.1.2. Local Programs	3-1
	3.1.3. Litigation of Source-Sampling Regulations	3-1
	3.2. Regulations Requiring Source Sampling and Monitoring	3-1
	3.2.1. Agency Tests	3-2
	3.2.2. Tests by the Owner-Operator	3-2
	3.3. Search Warrants	3-2
	3.4. Typical Statutes, Codes, and Regulations	3-3
	3.4.1. State Statutes	3-3
	3.4.2. Regulations of State and Local Agencies	3-4
4.	Legal Use of Source-Sampling Information	4-1
	4.1. Taking the Sample	4-1
	4.1.1. Test Equipment	4-1
	4.1.2. Test Personnel	4-2
	4.2. Transportation of the Sample	4-2
	4.3. Identification of Samples, Filters, and Containers	4-2
	4.4. Handling and Chain of Custody	4-3
	4.5. Laboratory Analysis and Calculations	4-3
	4.6. Custody of Final Report and Data	4-3
5.	Organization and Administration of a Source-Sampling Unit	5-1
	5.1. Organizational Plans	5-1
	5.2. Personnel Requirements	5-1
	5.2.1. Manpower Needs	5-1
	5.2.2. Test-Team Personnel	5-1
	5.2.3. Personnel Costs	5-7
	5.3. Equipment and Space Requirements and Associated Costs	5-8
	5.3.1. Equipment and Costs	5-8
	5.3.2. Space Requirements and Costs	5-8
	5.4. Administrative Procedures	5-8
	5.4.1. Request for Source Test	5-8
6.	Preliminary Procedures Required in Conducting a Stack Test	6-1
	6.1. Presurvey Process Information	6-1
	6.2. Selection of Test Site	6-1
	6.3. Preliminary Determination of Emission Parameters	6-5

7. Particulate Sampling Procedures 7-1
7.1. Measurement of Stack Gas Velocity and Related Parameters 7-1
7.1.1. Location of Traverse Points 7-1
7.1.2. Velocity Head Measurements 7-4
7.1.3. Temperature and Static-Pressure Measurements 7-6
7.1.4. Gas Density and Moisture Determination 7-8
7.1.4.1.Gas Density 7-8
7.1.4.2.Moisture Content 7-8
7.1.5. Calculation of Velocity and Total Gas Flow 7-9
7.2. Determination of Isokinetic Sampling Rates 7-9
7.2.1. Calculation Aides 7-10
7.3. Nonideal Sampling Conditions 7-13
7.3.1. Poor Flow Distribution 7-13
7.3.2. Nonisokinetic Sampling Conditions 7-13
7.3.3. Cyclic Flow Conditions 7-13
7.4. Particulate Sampling Equipment 7-13
7.4.1 Description of Sampling Train 7-13
7.4.2 Assembling and Testing the Train 7-16
7.4.2.1.Calibration of Train Components 7-16
7.4.2.2.Assembling Train Components 7-16
7.4.2.3.Testing the Sampling Train 7-17
7.5. Sampling Procedure 7-17
7.5.1. Location of Sampling Points 7-17
7.5.2. Length of Sampling Periods 7-17
7.5.3. Operation of Sampling Train 7-17
7.5.4. Recording Data during Test Period 7-19
7.5.5. Sampling Problems 7-19
7.6. Disassembly and Particulate Clean-out Procedure 7-19
7.7. Particulate Analysis 7-23
7.8. The Test Report 7-25
7.8.1. Format of Test Report 7-25
7.8.2. Presenting the Results 7-25
7.8.3. Example Calculations 7-25
7.8.3.1.Determination of Stack-Gas Volume 7-25
7.8.3.2.Determination of Sample Gas Volume 7-27
7.8.3.3.Check on Isokinetic Flow Rate 7-27
7.8.3.4.Converting to Other Emission Standards 7-27
8. Significance of Errors in Source Sampling 8-1
Appendix A. Nomographs for Use with Sampling Train A-1
Appendix B. Cleaning of Train Components B-1
Appendix C. Orifice Calibration Procedure C-1
List of Symbols S-1
References R-1

LIST OF FIGURES

		Page
5-1.	Organizational Chart of New Jersey Bureau of Air Pollution Control	5-2
5-2.	Organizational Chart of Technical Services and Special Investigation Section, New Jersey Bureau of Air Pollution Control	5-3
5-3.	Organizational Chart of San Francisco Bay Area Air Pollution Control District	5-4
5-4.	Organizational Chart of Engineering Section, San Francisco Bay Area Air Pollution Control District	5-5
5-5.	Organizational Chart of City of Chicago Department of Environmental Control	5-6
5-6.	Organizational Chart of Technical Services Division, City of Chicago Department of Environmental Control	5-6
5-7.	Source Test or Sample Analysis Request Form Used by Los Angeles Air Pollution Control District	5-10
5-8.	Automated Source Test Request Form Used by New Jersey Bureau of Air Pollution Control	5-11
6-1.	Sample Presurvey Form for Combustion Sources	6-2
6-2.	Sample Presurvey Form for Incinerators	6-3
6-3.	Sample Presurvey Form for Industrial Processes	6-4
7-1.	Minimum Number of Traverse Points	7-2
7-2.	Cross Section of Circular Flue Divided into Three Concentric Equal Areas, Showing Location of Sampling Points	7-3
7-3.	Cross Section of Rectangular Flue Divided Into 12 Equal Areas with Sampling Points Located at the Center of Each Area	7-3
7-4.	Typical Pitot Tubes Used to Measure Velocity Head	7-5
7-5.	Gas Velocity and Volume Data	7-7
7-6.	Correction Factor Nomograph	7-11
7-7.	Operating Nomograph	7-12
7-8.	Expected Errors Incurred by Nonisokinetic Sampling	7-14
7-9.	Particulate Sampling Train Used By Office of Air and Waste Management	7-15
7-10.	Particulate Field Sampling Meter Data	7-18
7-11.	Boiler Operating Data	7-20
7-12.	Incinerator Operating Data	7-21
7-13.	Process Operating Data	7-22
7-14.	Particulate Analysis Data	7-24
7-15.	Format for Presenting Emissions from Fuel Combustion Units	7-26
7-16.	Summary of Emission Test Data	7-28
7-17.	Particulate Sampling Calculations	7-29
A-1.	Correction Nomograph for Use with Figure A-2	A-2
A-2.	Operating Nomograph	A-3
C-1.	Orifice Calibration Form	C-2

LIST OF TABLES

		Page
5-1.	Examples of Source-Sampling Staffs of Various Agencies	5-7
5-2.	Relative Pay Scales of Technical Personnel by Region	5-8
5-3.	Space Requirements for Source-Sampling Programs	5-8
7-1.	Percent of Circular Stack Diameter from Inside Wall to Traverse Point	7-4
7-2.	Example Determination of Type S Pitot Tube Correction Factor	7-5

ADMINISTRATIVE AND TECHNICAL ASPECTS OF SOURCE SAMPLING FOR PARTICULATES

INTRODUCTION

This manual is provided by the Control Programs Development Division, Office of Air and Waste Management, Environmental Protection Agency, to assist state and local air pollution control agencies in obtaining a better understanding of the purposes and procedures of source sampling. This document presents general guidelines to show how source sampling can be part of an agency's program, the organization and approximate cost of such a program, regulations to permit source sampling, a detailed description of EPA procedures for particulate sampling, and other related material.

Organizational structures and functional duties of the source-sampling group cannot be exactly defined because these factors will vary with the overall structure of the control agency. Example organization charts and functions are presented, however. Sampling and analytical procedures likewise cannot be exactly defined for all cases because they will vary with the purpose of the test and the process sampled. Standards of performance for new stationary sources have been published in the December 23, 1971, *Federal Register*, Volume 36, No. 247, page 24876, with the associated methods and procedures. These methods should be followed in order to obtain results that are comparable from one test to another.

1. SOURCE–SAMPLING PURPOSES

Source sampling or emission testing, as applied to air pollution studies, is the procedure whereby a representative sample is removed from some larger, contaminant-bearing gas stream confined in a duct or stack. This sample is then subjected to further analysis, and the contaminant concentrations are related to the parent gas stream to determine total quantities. Because the sample extracted from the main gas stream usually represents a very small fraction of the total volume, extreme care should be exercised in obtaining a representative sample. Additionally, because of the many and variable factors encountered in sampling gas streams, complex methods must frequently be used to obtain representative samples.

Source sampling frequently is employed to answer a variety of questions of which the main one is: What are the quantities and concentrations of emissions? Subsequent questions that can be answered from this basic determination include:

1. Is the process in compliance with present or expected emission regulations?
2. What is the efficiency of existing pollution control equipment?
3. What effect do various process variables have on emissions?
4. Is a valuable product or by-product being emitted?
5. What are the potential (uncontrolled) emissions of various processes?

2. FUNCTIONS OF THE SOURCE-SAMPLING UNIT

The primary function of the source-sampling unit* is to obtain reliable emission data. The exact duties assigned to the source-sampling unit will vary widely from agency to agency, depending on the potential workload, the emission regulations, and the availability of other agency personnel when required. In small agencies, where source sampling may not be a full-time activity, source-sampling personnel may actually be part of some other unit such as engineering or technical services. In that case, when sampling is required, personnel will have to reschedule their other duties, perform the test work and analysis, and then return to their routine job.

On the other hand, a large agency with many requirements for source testing will have a full-time staff, including chemists, performing tests. Engineering technicians should maintain the sampling equipment, perform calibrations, assist in stack testing, and make routine calculations. The engineering staff should perform sampling-site surveys, plan the test procedures, set the schedule, supervise the actual tests, review calculations, and prepare the final report. In large source-sampling units, a chemist or senior chemical technician may be assigned to the sampling group. This person should be responsible for all routine lab analyses and serve as coordinator between the laboratory and the sampling units.

The source-sampling unit can also perform duties closely related to source sampling, such as determining or checking emission factors for various processes, developing and/or improving test methods and equipment, developing particle size distribution data, and preparing summary reports of emission data and related factors for presentation at technical meetings.

---

* For simplicity, the group of people comprising the source-sampling function is referred to as a unit. This unit could be referred to as a section, group, etc., depending on the agency's administrative breakdown.

† All methods used for compliance tests are subject to approval by the Office of Air and Waste Management.

2.1. SPECIFIC DUTIES ASSIGNED TO THE SOURCE-SAMPLING UNIT

Specific duties to be performed by the source-sampling unit in a larger agency include:

Technical Duties

1. Develop and update reliable source-testing procedures for particulate and gaseous emissions.†
2. Calibrate and maintain all equipment.
3. Plan and conduct source tests as required.
4. Perform and check all test calculations.
5. Prepare test reports and summaries of emission data.
6. Review source tests conducted by private firms.

Administrative Duties

1. Train personnel.
2. Procure equipment to conduct source tests.
3. Maintain a file of all source-test data.
4. Prepare annual reports and budget requirements.
5. Make contacts with plant personnel.
6. Schedule tests.
7. Coordinate source-test data with other agency activities.

The functions assigned to the source-sampling group in a small agency can be more varied because other duties will be performed in the interim between conducting source tests.

In addition to the technical duties connected with source sampling, the following duties can also be performed:

Additional Duties

1. Conduct a limited ambient air monitoring program.

2. Conduct emission inventories.

3. Assist in plan review and site inspections.

4. Perform routine laboratory analyses.

In smaller agencies, some of the engineering and administrative functions may be assumed by personnel in higher levels of supervision. Alternatively, the entire sampling function can be contracted out to a reliable consultant, and the administrative duties can be handled by the agency.

3. REGULATIONS REQUIRED TO CONDUCT SOURCE SAMPLING

3.1. STATUTORY AUTHORIZATION TO ESTABLISH PROGRAM

Air pollution control agencies possess only those powers specified by the appropriate legislative body in some type of enabling legislation. Generally, two steps are required before the agency can embark on a source-sampling program: (1) adoption of enabling legislation and (2) promulgation of regulations. The enabling legislation should establish that the air pollution control agency is empowered to maintain a source-testing program. The regulations should detail the program and refer to the test procedures, testing requirements, test frequencies, and emission limits.

3.1.1. State Programs

Most state air pollution control agencies have authority to inspect processes and equipment to determine compliance with equipment specifications and emission regulations. A deficiency in the statute may exist, however, if inspection powers are granted without specific mention of the administration of a testing program. On the other hand, in the absence of specific language authorizing source sampling, it is possible that the statute is sufficiently broad to reasonably infer that a testing program is to be implemented. Perhaps such an inference may be drawn from the stated purpose of the legislative grant of power to the agency. To guard against possible misinterpretations, enabling legislation should specifically mention inspection powers and source-sampling administration. The Federal Clean Air Act of 1970 requires that a state have authority to make inspections and test emission. A source-sampling program is essential to the enforcement aspects of an implementation plan.

After legal advice has been obtained regarding the adequacy of the enabling legislation, the state agency should develop administrative regulations consistent with the legislation. Although there are many existing regulations upon which administrative regulations can be based, there is no substitute for the assistance of legal counsel at the outset. Benefit can be derived, however, from a study of existing regulations, and the latter should not be ignored.

3.1.2. Local Programs

Many states have delegated to their various political subdivisions the authority to establish and maintain air pollution control programs. The Federal Clean Air Act, however, specifies that the primary responsibility for controlling air pollution lies with the states. When a state does delegate this authority, it must be ready to step in if the local entity fails to meet its obligations. For local programs, the specific entity—usually a county or health district—has to adopt emission source-sampling regulations. Local regulations must be no less stringent than the state's regulations. As with the state agency, the local political subdivision must determine that it has adequate authority to establish a source-sampling program; then it must adopt compatible regulations or ordinances.

In some states it may not be necessary for the state legislature to sanction local programs; that is, in the absence of statutory authority, it may be possible to establish and maintain a source-sampling program through the powers given to or retained by various state political subdivisions under the state constitution. Thus, various cities may maintain programs on the basis of their constitutionally granted home-rule powers. Again it should be emphasized that local program regulations must be no less stringent than the state regulations.

3.1.3. Litigation of Source-Sampling Regulations

Through 1969, no cases had been reported concerning the litigation of source-sampling regulations. A lot of activity has occurred, however, in the related area of search and seizure since the Supreme Court decision in *See v. City of Seattle*, 87 S. Ct. 1737 (1967). Search warrant requirements are discussed in Section 3.3.

3.2. REGULATIONS REQUIRING SOURCE SAMPLING AND MONITORING

State regulations requiring periodic reports on the nature and extent of emissions and the installation of emission-monitoring equipment are mandated

by the Clean Air Act as amended in 1970 [Sec. 110(a) (2) (F)]. The Act, as amended, also provides the Administrator of EPA with authority to promulgate regulations regarding the periodic testing and monitoring of emissions by the owner or operator of any stationary source [Sec. 114(a)]. Authority also exists for the Administrator to conduct source tests under certain conditions [Sec. 114(a) (2) (B)]. Basically, both the regulators and those regulated will conduct source tests.

3.2.1. Agency Tests

Although the primary responsibility for source testing rests with the process owner, the agency must have authority to conduct its own tests as a backup measure. The agency's regulations should consider the following:

1. Test Methods–Standardized testing methods are required. Regulations should specify that tests will be conducted in a manner determined by the director of the agency. These methods in turn should be approved by the Office of Air and Waste Management.

2. Equipment and Processes to be Sampled–Regulations should specify that all stationary sources are subject to testing by the agency.

3. Frequency of Tests–The director of the agency should have the authority to require source tests. Provisions should be made for testing when the agency has good cause to suspect emissions in excess of the regulatory limitations as determined by field inspections.

4. Employment of Independent Testers–For the smaller agencies especially, it may be desirable to provide for the employment of qualified independent testers.

5. Access to Facilities–Sampling ports, electrical power, platforms, and ladders are all necessary for source sampling. These facilities should be provided at the owner's expense and should be specified for all operations subject to the source-sampling requirements. Reasonable access to the test facilities should also be specified. Installation of these facilities can be incorporated in a permit system.

6. Test Costs–Regulations should specify an equitable allocation of costs. A general guideline might be to require full payment by the owner-operator in all cases if the test indicates that emissions are in excess of the regulatory limitations or if the test is being conducted pursuant to the issuance of the first operation permit. If emissions are below the regulatory limit, the owner-operator should not be charged.

3.2.2. Tests by the Owner-Operator

The owner-operator should be required to conduct tests pursuant to state and Federal regulations. The following items should be considered in preparing regulations:

1. Frequency of Tests–Tests should be made to provide the agency with information regarding the nature, extent, and quantity of emissions. After the initial test, the agency should be given the authority to require additional tests.

2. Test Certification–All tests should be certified by a professional engineer or witnessed by an agency representative.

3. Test Costs–The owner-operator should bear all costs incurred in making his own tests.

4. Test Methods–Standardized testing methods should be required. Regulations should specify that tests must be conducted in a manner determined by the director of the agency.

3.3. SEARCH WARRANTS

The necessity for the procurement of a search warrant as a condition precedent to source sampling must be considered in preparing a regulation. This area is a very fluid one at present. Leading cases in this area are *See v. City of Seattle*, 87 S.Ct. 1737 (1967); *People v. White*, 65 Cal. Rptr. 923 (1968); *United States v. Kramer Grocery Co.*, 418 F. 2d 987 (1969); and *Colonnade Catering Corp. v. United States*, 25 L Ed 2d 60 (1970).

The decision to design a regulation that will alleviate the need for search warrants is up to the agency. Such a regulation will require the advice of the agency's legal counsel and should take into consideration the following factors:

1. The entrance, inspection, and testing should be connected to a bona fide licensing or permit system.

2. Penalty provisions should not be designed so as to indicate that they constitute the sole sanction, without a warrant, to enter.

3. Consent to test should be obtained in advance with the issuance of the license or permit.

3.4. TYPICAL STATUTES, CODES, AND REGULATIONS

Typical statutes and regulations promulgated in jurisdictions that have established air pollution control agencies are presented in this Section to show how the various factors discussed in the first three Sections of this chapter may be integrated into statutes, codes, and regulations. These statutes and regulations cover state statutes, regulations of state agencies, and regulations of local agencies, all of which pertain to source sampling.

3.4.1. State Statutes

The enabling legislation of the State of Ohio (ORC §3704.03) reads as follows:

Sec. 3704.03 Powers of board.
The air pollution control board may:

(K) Through any individual member or any representative authorized by the board, enter upon private or public property, including improvements thereon, at any reasonable time for the purpose of determining if there are any emissions from such premises, and if so, to determine the sources and extent of such emissions;

Entry by the board, an authorized employee, or consultant

Source sampling

The New Jersey law (N.J.S.A. §26:2c-9) provides:

The department shall control air pollution in accordance with the provisions of any applicable code, rule, or regulation promulgated by the department and for this purpose shall have power to–

(d) Enter and inspect any building or place, except private residences, for the purpose of investigating an actual or suspected source of air pollution and ascertaining compliance or noncompliance with any code, rules and regulations of the department. Any information relating to secret processes or methods of manufacture or production obtained in the course of such inspection, investigation or determination, shall be kept confidential and shall not be admissible in evidence in any court or in any other proceeding except before the department as herein defined. If samples are taken for analysis, a duplicate of the analytical report shall be furnished promptly to the person suspected of causing air pollution;

Promulgation of regulations

Source sampling

The Kentucky law (KRS §224.370) reads:

224.370 Inspection of premises; interference unlawful. Any duly authorized officer, employee, or representative of the commission may enter and inspect any property, premise, or place at any reasonable time for the purpose of investigating either an actual or suspected source of air pollution or of ascertaining the state of compliance with KRS 224.310 to 224.460 and 224.991 and regulations enforced pursuant thereto. No person shall refuse entry or access to any authorized representative

Entry by the commission, an authorized employee, or consultant

Source sampling

of the commission who requests entry for purposes of inspection and who presents appropriate credentials; nor shall any person obstruct, hamper, or interfere with any such inspection. (1966, c. 22, § 9)

Illinois has just passed a comprehensive Environmental Protection Act. Section 10 of that Act reads in part:

Adoption of regulations including broad power for inspection

Section 10. The Board, pursuant to procedures prescribed in Title VII of this Act, may adopt regulations to promote the purposes of this Title. Without limiting the generality of this authority, such regulations may among other things prescribe;
(f) Requirements and procedures for the inspection of any equipment, facility, vehicle, vessel, or aircraft that may cause or contribute to air pollution;

3.4.2. Regulations of State and Local Agencies

The Commonwealth of Kentucky Air Pollution Control Commission has adopted the following testing requirements for indirect heat exchangers in the Commission's Regulation 7:

Frequency of tests

Costs of test

(1) Whenever the Kentucky Air Pollution Control Commission has reason to believe that the emission limits of this Regulation are being violated, it may require the owner to conduct or have conducted at the owner's expense, tests to determine the particulate matter emission level, which tests shall include stack tests if circumstances so demand. The Kentucky Air Pollution Control Commission may request that such tests be conducted in the presence of Commission representatives.

Certification of test

(2) Should the Kentucky Air Pollution Control Commission wish to conduct tests of its own to determine compliance with emission limits of this Regulation, the owner shall provide at no expense to the Kentucky Air Pollution Control Commission, reasonable and necessary openings in stacks, vents, and ducts, along with safe and easy access thereto including a suitable power source to the point of testing.

Tests by state agency

Test facilities and access

(3) The Kentucky Air Pollution Control Commission shall be supplied with such data as it may require to establish test conditions.

Test procedures (should be updated)

(4) Stack tests for particulate matter shall be made by methods found in ASME "Power Test Code PTC 27," dated 1957, titled, "Test Code for Determining Dust Concentrations in Gas Streams" or by such other methods approved by the Kentucky Air Pollution Control Commission.

Variance of procedure at discretion of agency

Kentucky's Regulation 8, Section 6, also provides for source testing as a condition for the issuance of a use permit.

Permits issued hereunder shall be subject to such terms and conditions set forth and embodied in

the permit as the Commission shall deem necessary to insure compliance with its standards. Such terms and conditions may include maintenance and availability of records relating to operations which may cause or contribute to air pollution including periodic source or stack sampling of the air contaminant sources.

Periodic sampling by licensee

Acceptance of a permit conditioned as described herein shall denote agreement to the restrictions embodied in the permit and shall thenceforth be binding upon the holder of the permit.

Consent to inspect and test

The City of Chicago Ordinance 17-2.52 provides a comprehensive testing regulation:

17-2.52 The commissioner is hereby authorized to conduct or cause to be conducted, any test or tests as may be necessary to determine the extent of emission of particulate matter from any fuel-burning, combustion or process equipment or device, if and when, in his judgment, there is evidence that any such equipment, process or device is exceeding any emission limitation prescribed by or under this chapter. The result of any test shall be made available to the person responsible for such property tested. Tests shall be made and the results calculated in accordance, where applicable, with American Society of Mechanical Engineers "Power Test Codes, Test code for determining dust concentration in a gas stream PTC-27-1957" procedure as revised from time to time or in accordance with modified procedures mutually agreed upon between the commissioner and the person. All tests and calculations shall be made under the direction of a competent engineer. Any test or tests to be conducted on the premises where such equipment or device is located shall be made during reasonable hours, after written notice to, and with the cooperation of, the owner or operator. The cost of any test or tests and calculations shall be a debt due the city from any person responsible as owner, operator or otherwise of such fuel-burning combustion or process equipment or device in all cases when such test or tests shall have proven any emission of particulate matter in violation of any provision of this chapter, and such unpaid debt shall be recoverable in any court of competent jurisdiction. If any such emission is shown by such test or tests to be within the limits of emission prescribed in this chapter, the cost of such test or tests shall be charged to the annual appropriation of the department.

Tests by commissioner, an employee, or consultant

Equipment to be used

Frequency of tests

Test procedures (should be up-dated)

Procedures may be modified at commissioner's discretion with owner's approval

Owner cooperation; test cost

The City of Cleveland's authority to test is given in Chapter 5 of the Air Pollution Code. Section §4.0502 reads in part:

§4.0502. Duties of Commissioner.

The Commissioner of Air Pollution Control under the supervision and direction of the Director of Public Health and Welfare shall:

F. Make inspections and tests of existing and newly installed equipment subject to this ordinance to determine whether such equipment complies with this code;

Complete details of source-sampling requirements are then given in Chapter 17 of the same Code:

§4.1702. Sampling and Testing.

(A) The Commissioner of Air Pollution Control is hereby authorized to conduct, or cause to be conducted, any test or tests of any new or existing process, fuel-burning, refuse-burning, or control equipment the operation of which in his judgment may result in emissions in excess of the limitations contained in this ordinance or when the emissions from any such equipment may exceed the limits of emissions provided for herein. All tests shall be conducted in a manner determined by the Commissioner and a complete detailed test report of such test or tests shall be submitted to him. When tests are taken by the owner or independent testers employed by the owner, the Commissioner shall require that the said tests be conducted by reputable, qualified personnel and shall stipulate that a qualified representative or representatives of the Division of Air Pollution Control be present during the conduct of such tests. The Commissioner may stipulate a reasonable time limit for the completion of such test and the submission of test reports.

Tests by the Commissioner or authorized representative

Test procedures

Tester qualifications

(B) Nothing in this section concerning tests conducted by and paid for by any person or his authorized agent shall be deemed to abridge the rights of the Commissioner or his representatives to conduct separate or additional tests of any process, fuel-burning, refuse-burning, or control equipment on behalf of the City of Cleveland, whether or not such tests relate to emissions controlled by specific limitations under this code.

§4.1703. Test Facilities and Access.

(A) It shall be the responsibility of the owner or operator of the equipment tested to provide, at his expense, utilities, facilities and reasonable and necessary openings in the system or stack, and safe and easy access thereto, to permit samples and measurements to be taken. All new sources of air contaminants created after the effective date of this ordinance may be required by the Commissioner of Air Pollution Control to provide utilities, facilities and adequate openings in the system or stack, and safe and easy access thereto, to permit measurements and samples to be taken.

Testing facilities and access

(B) When any process equipment, fuel-burning equipment or refuse-burning equipment has caused an air pollution nuisance, as determined by the Commissioner, or has violated a provision of Chapter 11, 13 or 15 of this code, the Commissioner may, at his discretion require that said equipment be equipped with an air contaminant recording device with an audible alarm set so as to become activated upon reaching prohibited levels of emission, which device shall be maintained in proper operating conditions at all times. Records from such recording device shall be made available to the Commissioner for periods up to one year.

§4.1704. Test Costs.

If emission tests conducted as a result of the action of the Commissioner of Air Pollution Control substantiate that a violation exists, the person or persons responsible for the violation shall be responsible for paying all attendant costs for conducting said tests. If said tests do not show that a violation exists, then the City shall be responsible for paying all costs for conducting the said test. In no event shall the city assume costs of providing facilities, utilities and access for such testing. When the person responsible elects to conduct his own stack emission tests, then the person so electing shall pay for the test or tests notwithstanding other provisions of this section, and irrespective of the result. The costs of emission tests required by the Commissioner on newly installed equipment for the issuance of the initial permit to install and the issuance of the initial certificate of operation shall not be at the expense of the City of Cleveland regardless of results. The tests for existing sources relating to contaminants not specifically controlled by this code shall be at the expense of the City of Cleveland except for facilities, utilities and access required to be provided by this Chapter.

Test costs

Test costs

Cost of providing test facilities

§4.1705. Circumvention and Right of Entry.

(A) No person shall build, erect, install, or use any article, machine, equipment, or other contrivance, the sole purpose of which is to dilute or conceal an emission without resulting in a reduction in the total release of air contaminants to the atmosphere nor shall a person do any thing nor commit any act with the intent to distort stack test emission results.

(B) Any person who in any manner hinders, obstructs, delays, resists, prevents, or in any manner interferes or attempts to interfere with the Commissioner or his representatives in the performance of any duty enjoined, or shall refuse to permit the Commissioner or such representatives to perform their

duty by refusing them, or either of them, entrance at reasonable hours to any premises in which the provisions of this ordinance are being violated, or are suspected of being violated, or refuse to permit testing, or permit the inspection or examination of such premises for the purpose of the enforcement of this ordinance shall be subject to cancellation of the certificate of operation, or such other action as may be provided at law or by provisions of this code.

4. LEGAL USE OF SOURCE-SAMPLING INFORMATION

Every test should be conducted as if it were ultimately to be used as evidence in court. The collection and analysis of source samples should become a routine matter to the agency personnel involved. It must be remembered, however, that this routine procedure is too esoteric for the layman and therefore subject to greater scrutiny whenever the agency has to rely on its results. It is imperative that source sampling and analysis be done under standard procedures and that each step be well documented. In short, the report may ultimately be subjected to the requirements of the Rules of Evidence.

This chapter will discuss the standardization of source-sampling procedures relative to taking the sample, chain of custody, laboratory analysis, report custody, and disposition of the original work sheets.

4.1. TAKING THE SAMPLE

In attacking the validity of source-sampling results, the adverse party will concentrate on four main items relative to taking the sample: (1) sampling procedure, (2) recorded data and calculations, (3) test equipment, and (4) qualifications of the testing personnel.

Agency personnel must be aware of the possibility of adverse inferences that may arise from the use of unorthodox or new procedures. Thus, deviations from the standard procedure must be kept to a minimum and applied only where absolutely necessary to obtain an accurate sample. Changes in methodology must be based on sound engineering judgment and must be carefully documented. Standard procedures that should receive particular attention are:

1. Location of sampling station.
2. Number and size of sampling zones in the duct.
3. Use of recommended sampling equipment.
4. Careful determination of gas velocities.
5. Maintenance of isokinetic sampling conditions.
6. Proper handling of the collected sample and recording of container and filter numbers.

Close scrutiny will also be focused upon the recorded field data because these data form part of the physical evidence. Standardized forms should be utilized to ensure that there is no lack of necessary information. Example forms designed for this purpose are included in Chapter 7; they consist of field, laboratory, and calculation forms. Only the field form is utilized when taking the sample. This form is designed to identify clearly the process tested, the date and time, location of test station, sampling personnel, and the person who recorded the data. During the actual test period, the meter readings, temperature readings, and other pertinent data should be recorded in the provided spaces immediately upon observation. These data determine the accuracy of the test and should not be erased or altered. Any errors should be crossed out with a single line, and the correct value should be recorded above the crossed-out number.

4.1.1. Test Equipment

Faulty test equipment can also invalidate a test. In general, there are two types of field test equipment, gas-sampling and process-measuring equipment.

The process-measuring equipment consists of any of the metering devices by which test data are obtained. These devices include scales for weighing fuel or raw materials and orifices and gauges for measuring product flow. Because proper maintenance and calibration procedures are often lacking, it cannot be assumed that these devices are accurate. In any case, check and record the date on which the device was serviced.

Ideally, the use of process-measuring equipment should be kept to a minimum. Process-weight regulations, however, may frequently require the use of such equipment, especially scales. Such scales can only be properly serviced and calibrated by specially trained personnel. The scale manufacturer usually provides this service. A stamp affixed to the scale by the service crew as a standard procedure will note the date of calibration or inspection. If the scale has not been recently calibrated, an engineering judgment must be made concerning its accuracy. A material balance will sometimes provide a check on scale readings.

Other equipment such as flow meters and gauges should be properly maintained and used. If there is reason to believe that the equipment is defective, the reason for the belief should be noted on the Field Data Form, and an engineering judgment on the validity of the data should be made.

Gas-sampling equipment that requires maintenance and calibration include the pitot tube, manometers, thermometers, flow meters, and dry gas meters. The maintenance of these instruments is subject to even greater scrutiny in court. Thus, written maintenance records must be kept. Suggested maintenance procedures are as follows:

Pitot Tube–The pitot tube should be calibrated when acquired. Subsequent calibration is not required, but a visual check should be made and noted prior to each test series (Section 7.1.2).

Manometers–Because the insides of the manometer tubes are subjected to the flue gas, the specific gravity of the oil may change if evaporation occurs. Readings also become difficult as dirt coats the glass tube. It is suggested that the manometers be washed with soapy water and the oil be replaced after every sixth test series. Note that the specified oil must be used.

Thermometers–Because dial-type thermometers, which are frequently used in the field, can be damaged easily, they should be checked prior to each test series. The check should be made against a mercury thermometer at approximately ¼ and ¾ of full scale. Thermocouples and associated recording equipment must also be calibrated periodically. Such calibrations should be made at least every 6 months.

Dry Gas Meter–The dry gas meter should be calibrated prior to each test series. This high frequency of calibration is recommended because of the relatively severe conditions under which the meter is used. It is subject to being bumped, dropped, vibrated, or even carried upside down. The best method of testing is with a positive-displacement calibrator such as a Bell-type Prover or a calibrated orifice.

4.1.2. Test Personnel

The sample must be taken by experienced personnel. Although it is not necessary that the chief of the field team be a professional engineer, he must have special training that qualifies him for source sampling. If the report is used in court, the chief of the field team may be called as a witness. Because poor data may be inadmissible as evidence, the chief should have previous experience as an aide on field tests, and, preferably, he should have received special training in source sampling. (Section 5.2 describes personnel duties in greater detail.)

One man alone usually cannot perform a source test. Two men are normally required for one test station, and a minimum of three are required for two stations. It is often difficult to record accurately the large amount of required data if the team is inadequately manned.

4.2. TRANSPORTATION OF THE SAMPLE

In transporting the sample to the laboratory, it is of primary importance that precautions be taken to eliminate the possibility of tampering, accidental destruction, and/or physical and chemical action on the sample.

To reduce the possibility of invalidating the results, all components of the sample must be carefully removed from the sampling train and placed in sealed, nonreactive, numbered containers. The sample should then be delivered to the laboratory for analysis. It is recommended that this be done on the same day that the sample is taken. If this is impractical, all the samples should be placed in a carrying case (preferably locked) in which they are protected from breakage, contamination, and loss.

4.3. IDENTIFICATION OF SAMPLES, FILTERS, AND CONTAINERS

Care must be taken to properly mark the samples to ensure positive identification throughout the test and analysis procedures. The Rules of Evidence require impeccable procedures for identification of samples, the analysis of which is the basis for future evidence. An admission by the lab analyst that he could not be positive whether he analyzed sample No. 6 or sample No. 9, for example, could destroy the validity of the entire report.

Positive identification also must be provided for the filters used in any specific test. All identifying marks should be made before taring. Three digits should ensure the unique identification of filters for many years. The ink used for marking must be indelible and unaffected by the gases and temperatures to which it will be subjected. If another method of identification is desired by the agency, it

should be kept in mind that the means of identification must be positive and must not impair the capacity of the filter to function.

Finally, each container should have a unique identification to preclude the possibility of interchange. The number of the container should be recorded on the analysis data sheet (Figure 7-14); thus it would then be associated with the sample throughout the test and analysis.

4.4. HANDLING AND CHAIN OF CUSTODY

The samples should be handled only by persons associated in some way with the task. A good general rule to follow is "the fewer hands the better," even though a properly sealed sample may pass through a number of hands without affecting its integrity.

It is generally impractical for the analyst to perform the field test. The Rules of Evidence, however, require that the prosecution be able to prove the chain of custody of the sample. For this reason, each person must be able to remember from whom he received the sample and to whom he delivered it. This requirement is best satisfied by having each recipient sign a receipt or the data sheet for the sample or set of samples. The process owner should also be given a receipt for the collected sample.

4.5. LABORATORY ANALYSIS AND CALCULATIONS

Potential sources of error in the analysis of the sample lie in the analyzing equipment, procedures, documentation of results, and qualifications of the analyst.

Laboratory equipment, especially the analytical balance, should be subjected to a routine maintenance program just as the field equipment is.

Analytical Balance—Balances require periodic calibration. It is recommended that calibration be done at least biannually, with Class M weights. Dates of calibration should be recorded.

Reagents—Only reagent-grade chemicals should be used. Reagents used in an Orsat or similar gas analyzer should be replaced periodically, depending on their use.

As with the field procedures, the laboratory data and calculations must be well documented. The use of standardized forms is recommended. In all cases the person who performs the analysis and/or calculations should sign the data sheet.

4.6. CUSTODY OF FINAL REPORT AND DATA

The team chief is responsible for the compilation of the test report under the supervision of a senior engineer who reviews it for content and technical correctness. The ultimate use of the report as evidence of a violation is the responsibility of the agency's supervisory management. The latter echelon makes the final determination as to whether or not the report is a correct representation of the field conditions.

Usually, written documents are considered to be hearsay and, therefore, not admissible as evidence without a proper foundation. A proper foundation can be laid by having the principal author(s) introduce the report. Thus the chief of the field team and the laboratory analyst would both be required to testify to lay the foundation for the introduction of the test report as evidence. The foundation laying is greatly simplified, however, though still required, under statutory exceptions to the Hearsay Rule found in the Official Reports as Evidence Acts and Business Records as Evidence Acts, which various states have adopted.

The rationale of the Official Reports exception lies behind the belief that a public officer performing a particular duty performs that duty properly and is under no motive to distort the truth. Basically, the Official Reports exception exists to avoid the necessity and expense of calling as witnesses various persons who may have collaborated in making the records.

To ensure the benefit of these statutory exceptions to the Hearsay Rule, the source-test reports should be filed in a safe place by a file custodian who has responsibility for the files. Once the report has been approved, a summary copy should be sent to the requester for further disposition. Generally, the field notes and calculations need not be included in the summary report. All this material may be required at a future date, however, to bolster the acceptability and credibility of the report as evidence in an enforcement proceeding. The full report, including all original notes and calculation sheets, should therefore be kept in the file. Signed receipts for all samples should also be filed with the test data.

Public records are subject to the Best Evidence Rule, which basically states that the original of a document is the best evidence and thus a mere copy is not admissible as evidence. Microfilm, snap-out carbon copies, and similar contemporary business methods of producing copies are acceptable in many jurisdictions, however, if the original is not reasonably available, its unavailability is adequately explained, and the copy was made in the ordinary course of business.

5. ORGANIZATION AND ADMINISTRATION OF A SOURCE-SAMPLING UNIT

5.1. ORGANIZATIONAL PLANS

The source-sampling unit must fit into the agency's organization in such a manner that the needs of the agency are met within the bounds of available resources. Because parameters vary so widely from area to area, it is impossible to define an ideal overall organizational structure. The main variables in the organization of source-sampling operations, however, are the number and complexity of the processes that must be tested and the functions to be performed by the unit.

Structuring the agency's source-sampling operations requires consideration of so many variables that no one type of organization can be recommended. Figures 5-1 through 5-6 show the structure of three agencies that have established comprehensive source-sampling programs. These figures are presented as examples to show how the test program relates to the overall program, and to show the actual organization of the source-sampling unit.

When many diverse, well-defined processes are located within an agency's jurisdiction, it is frequently advisable to utilize personnel with expertise in specific processes as supervisors of the source test teams. The number and designation of the supervisors will, of course, depend on the processes to be sampled. Unless an extremely large amount of specialized testing is required, all-purpose teams are more efficient. The expertise of the engineer who functionally supervises the test team, coupled with the testing team's basic background, should result in reliable and efficient tests.

The title given to the source-sampling supervisor will depend on the size and organization of the agency. For the smaller agencies, the supervisor could have several units under him – perhaps the laboratory and ambient air monitoring sections in addition to the source-sampling unit. In some agencies he may be the Chief Air Pollution Control Officer.

5.2. PERSONNEL REQUIREMENTS

5.2.1. Manpower Needs

Estimating the manpower needs of a source-sampling operation is difficult because so many factors are involved; the final determination of the number of people will depend on the specific workload. Table 5-1 shows the manpower needs of three existing programs: state, multicounty, and city. Because these are successful programs, the two factors used in a recent manpower model are also displayed in the table to provide some perspective. It should be noted that the current manpower needs shown in Table 5-1 are compared with 1963 data. The manpower model predicts that an agency must service at least 4,000 manufacturing establishments having annual capital expenditures totaling over $200 million before more than three source-test personnel are required. Statewide capital expenditures of manufacturing establishments during 1967 were greater than $200 million in 31 states and less than $400 million in 26 states.

The 1970 Amendments to the Clean Air Act, however, require greater source-test efforts by state and local agencies. Because the manpower model was based on the pre-1970 Act, it may tend to underpredict the number of required source-testing personnel. This factor should be kept in mind when using the model.

5.2.2. Test-Team Personnel

Location and access to the sampling ports determine the size of the basic testing team. In general, two men are required for each sampling station. Agencies currently find that the team chief can adequately supervise two two-man teams testing at different sites. The added work of taking concurrent samples before and after the control equipment, however, may require a full-time fifth man.

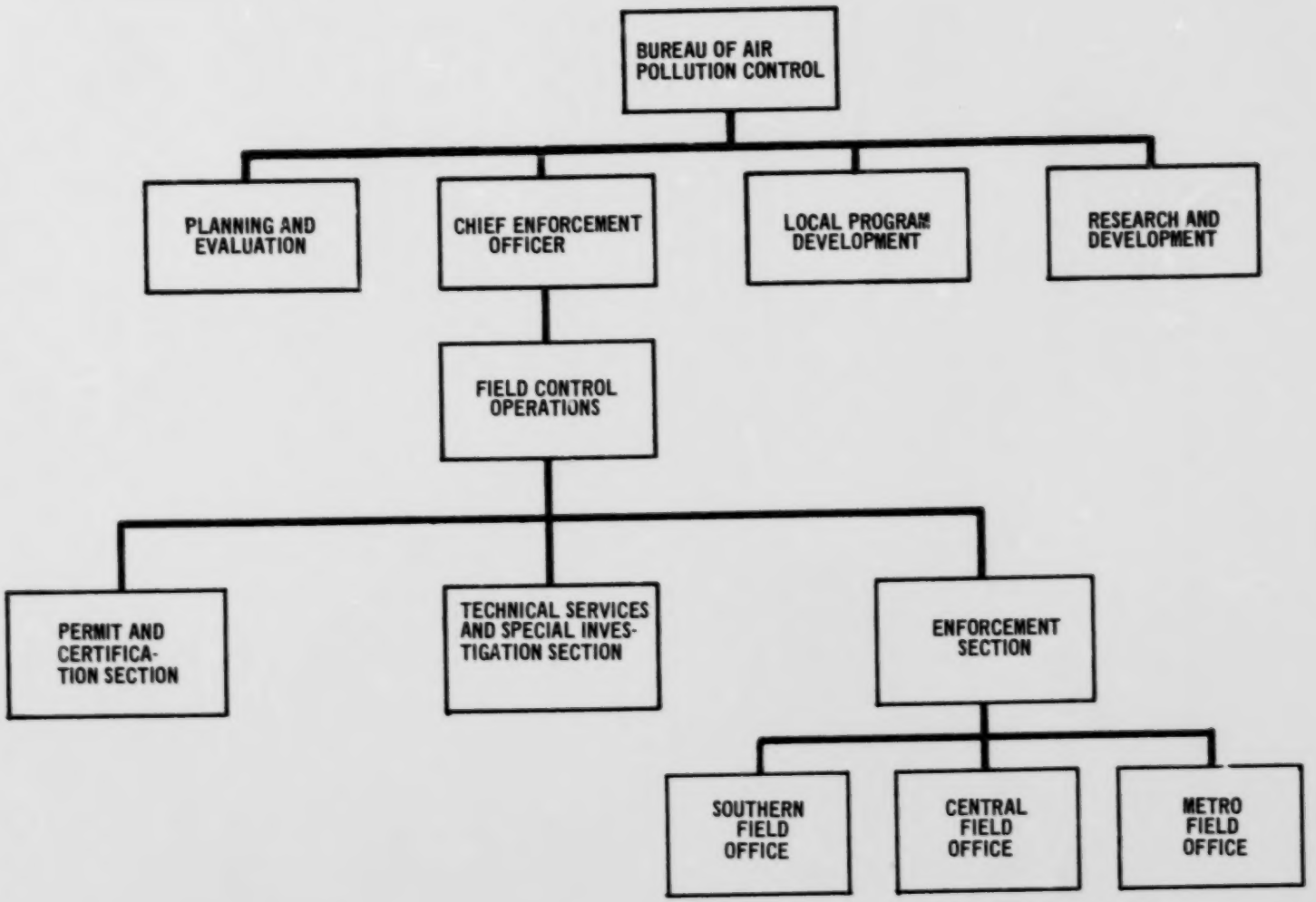


Figure 5-1. Organizational chart of New Jersey Bureau of Air Pollution Control.

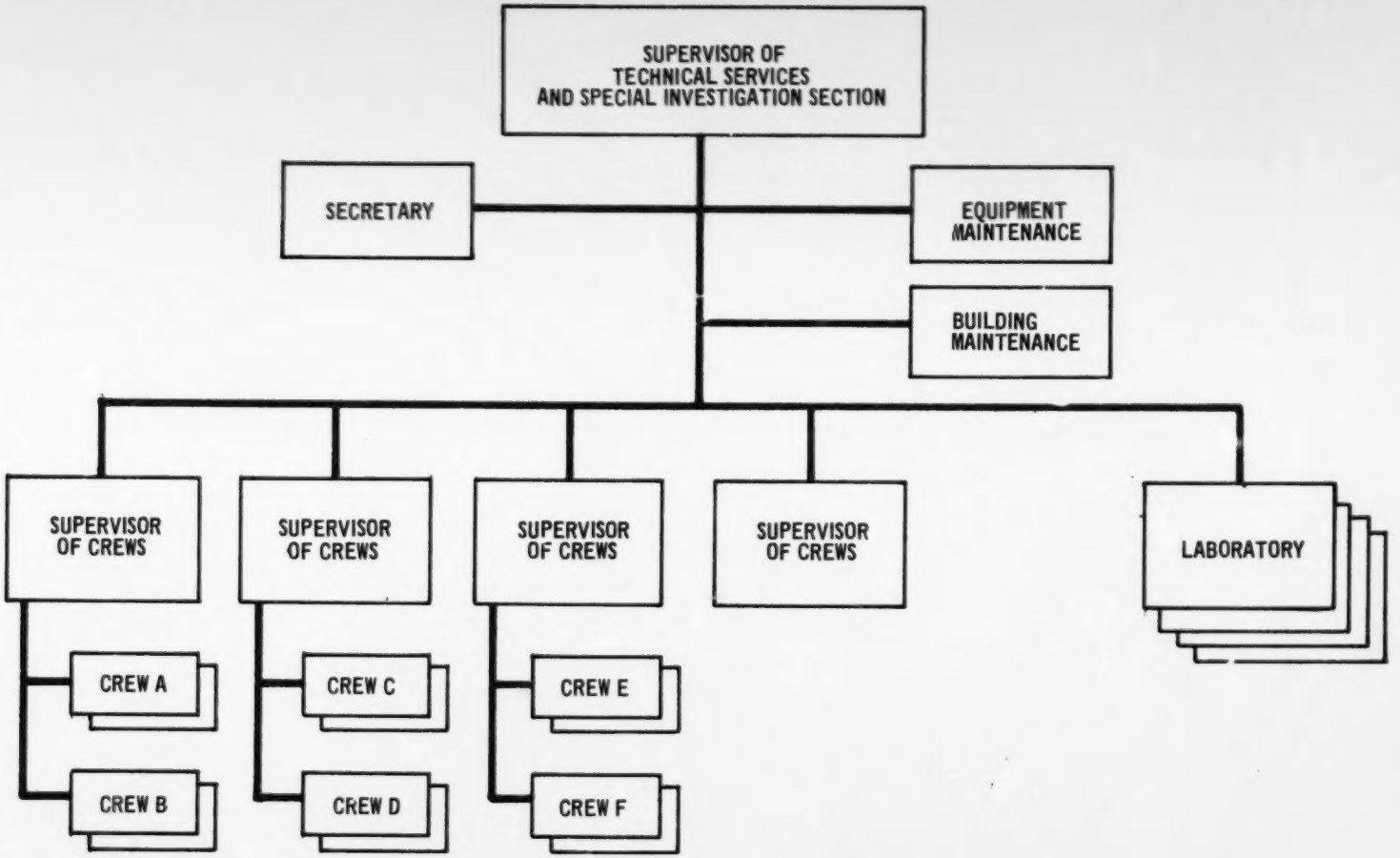


Figure 5-2. Organizational chart of Technical Services and Special Investigation Section, New Jersey Bureau of Air Pollution Control.

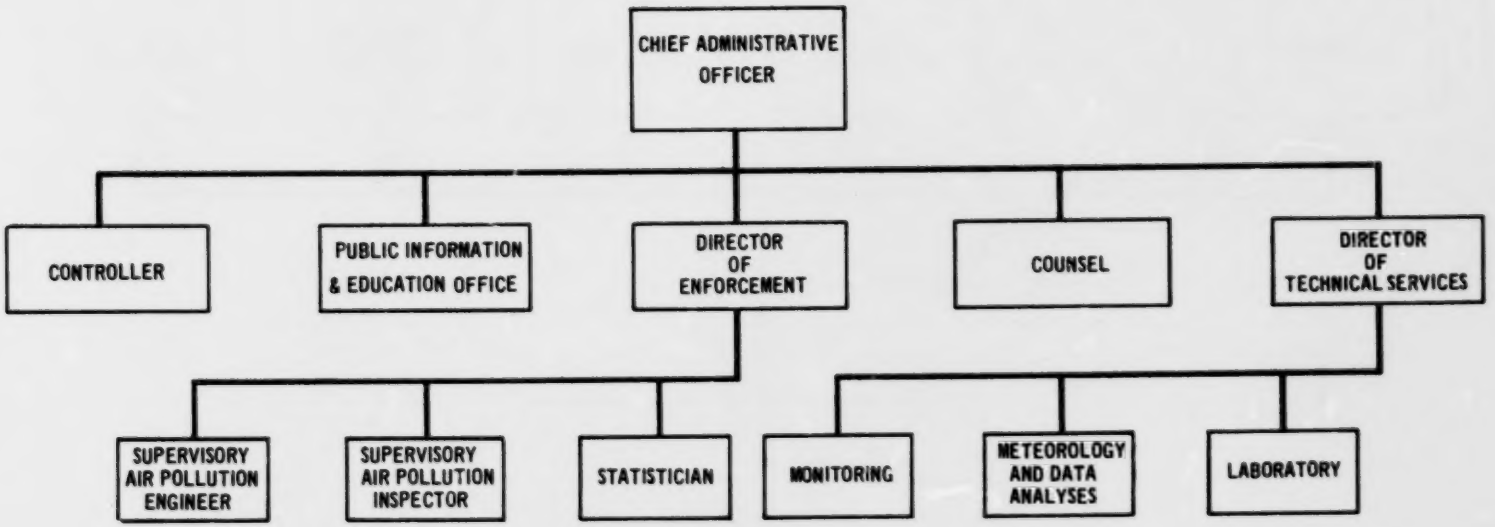


Figure 5-3. Organizational chart of San Franciscc Bay Area Air Pollution Control District.

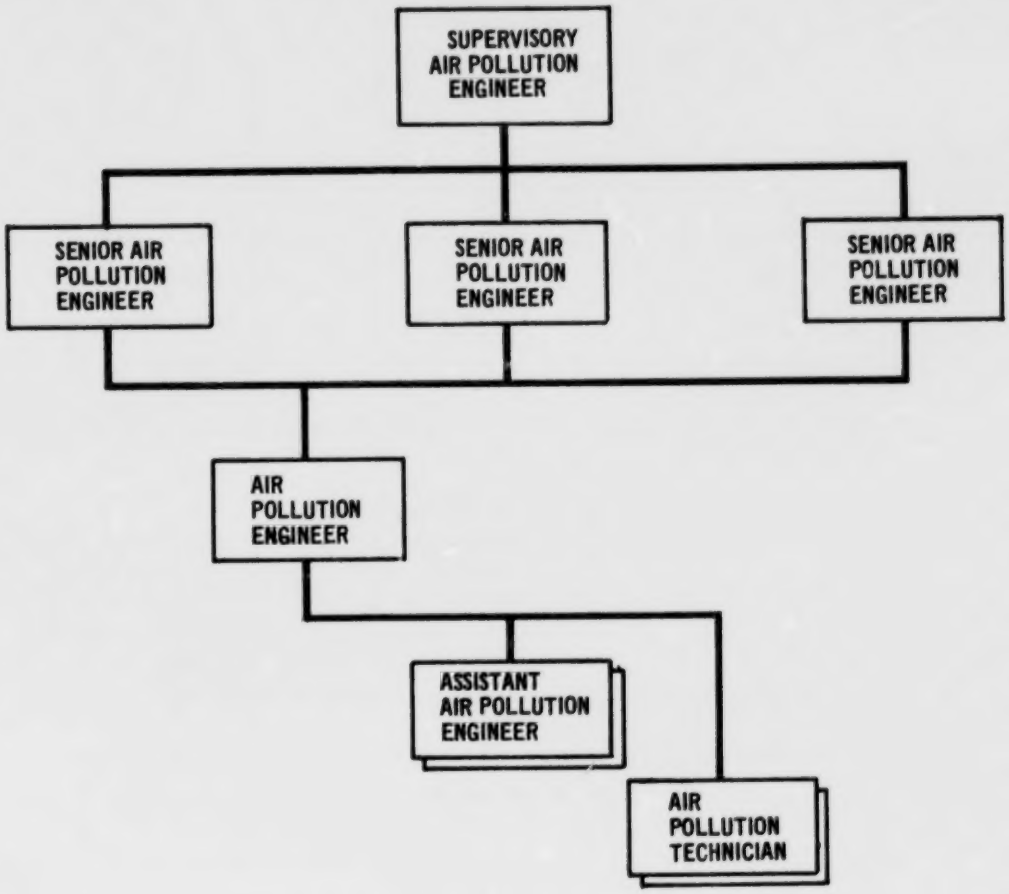


Figure 5-4. Organizational chart of Engineering Section, San Francisco Bay Area Air Pollution Control District.

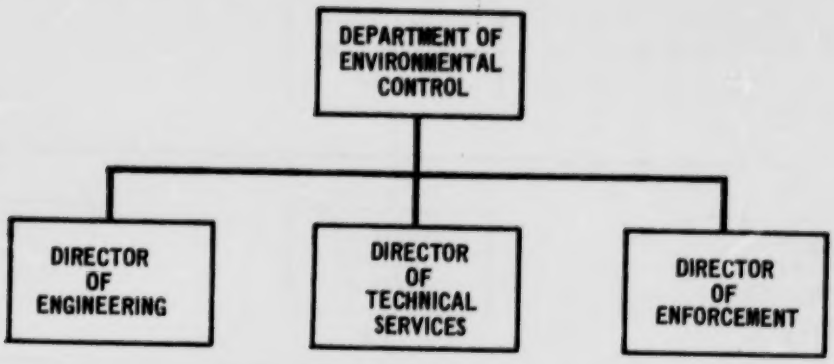


Figure 5-5. Organizational chart of City of Chicago Department of Environmental Control.

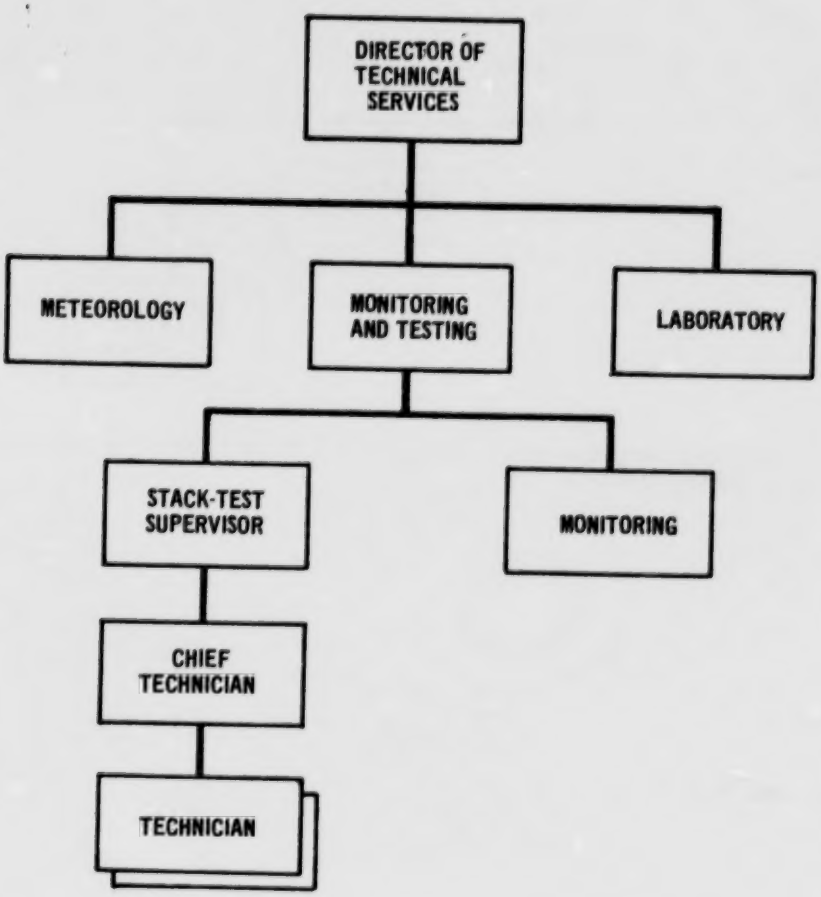


Figure 5-6. Organizational chart of Technical Services Division, City of Chicago Department of Environmental Control.

Table 5-1. EXAMPLES OF SOURCE–SAMPLING STAFFS OF VARIOUS AGENCIES

Agency	Actual number of source-testing personnel [a]	Number of manufacturing establishments [b]	Annual capital expenditures of manufacturing establishments, 10^6
State of New Jersey	4 Team chiefs 12 Technicians [c] (6 teams) 1 Equipment maintenance man	15,200	525 (785) [d]
San Francisco Bay Area Air Pollution Control District	3 Sr. engineers 1 Team chief 4 Technicians (2 teams)	6,000	250
City of Chicago	1 Sr. engineer 3 Technicians (1 team)	9,200	230

[a] Excludes supervisor, secretary, laboratory, and other personnel not directly related to testing (1970 data).

[b] Source: County and City Data Book, 1967, U.S. Department of Commerce. Reported data are rounded off for purposes of this table (1963 data).

[c] Current plans are for the addition of two more technicians.

[d] 1967 data shown for comparison only. Source: U.S. Bureau of the Census, Statistical Abstract of the United States: 1969, Table No. 1110.

The technicians serving on the test teams should have a basic understanding of source-sampling principles. Technicians usually take samples, record field data, and sometimes weigh samples and filters. Technicians are generally responsible for maintenance and calibration of the test equipment.

The team chief is directly responsible for all the field work and should have a background in engineering or industrial hygiene. In smaller programs, because he reports directly to the program supervisor, he should be an engineer. In general, the team chief plans the test, supervises the actual extraction of the sample, and may transport the samples to the laboratory. The team chief should also check all calculations.

In larger programs, the team chiefs will usually report to a senior engineer. Preferably, the senior engineer should be a professional engineer and have a broad knowledge of the various industrial processes within the agency's jurisdiction. Because he is responsible for all tests, he should be experienced in source sampling and be able to establish rapport with process operators. The senior engineer is usually the agency's expert witness in matters involving emission testing.

5.2.3. Personnel Costs

Estimated ranges of salary requirements for the various functional positions are presented to indicate the approximate personnel costs of a source-sampling program. The greatest salary range, which exists at the technician level, represents the spread between the novice and the experienced technician. Other positions are affected mainly by experience, agency size, and geographical location. Approximate base-salary ranges are as follows:[2]

Supervisor	$15,000 to $23,500
Senior Engineer	$13,000 to $19,500
Team Chief	$11,000 to $17,000
Technician	$ 7,000 to $13,000
Secretary	$ 5,000 to $ 7,000

Overhead rates associated with the base salary must be included for budgeting. In general, the New England and Middle Atlantic regions are areas of highest pay. Table 5-2 lists the various geographic areas with relative salaries listed as percentages of the New England scale.

Table 5-2. RELATIVE PAY SCALES OF TECHNICAL PERSONNEL BY REGION[a]

Region	Relative salaries, %
New England	100
Middle Atlantic	100
South	92
Midwest	89
Plains	84
Southwest	87
West	92

[a]Based on 1969 survey conducted by the National Society of Professional Engineers.

5.3. EQUIPMENT AND SPACE REQUIREMENTS AND ASSOCIATED COSTS

5.3.1. Equipment and Costs

This section describes the major items of equipment required for a source-sampling program. Incidental items such as clamps, heating wire, safety equipment, miscellaneous hardware, and the various pieces of workshop equipment will not be discussed. Section 7.4 presents a detailed discussion of specific equipment needs.

At least two complete sampling trains are required. These trains include the nozzles and probe, cyclone/filter collector, impingers, pump and meter assembly, and associated equipment. In addition, the agency will minimally require a desiccator and analytical balance for drying and weighing the samples. Provisions must be made for calibrating the dry gas meters. A spirometer or Bell-type Prover is the best equipment for this purpose. These devices are very expensive, however, and, whenever possible, arrangements with the local gas utility company for periodic calibration should be made. A carefully calibrated orifice may also be used for calibration. If the regulations require correction to 12% CO_2 or a similar basis, an Orsat apparatus will be required.

Each team requires a vehicle for transportation of equipment (a panel truck or station wagon will suffice). In addition, the senior engineer or team chief may require a vehicle for field use.

A complete single set of particulate sampling equipment costs approximately $3,500. Associated laboratory equipment and miscellaneous hardware, which can be shared by more than one team, cost about $2,000. Associated equipment costs should include maintenance and depreciation of all equipment and motor vehicles used by the program. Such items as office supplies and furnishings are not included, however. Travel costs, personnel overhead, and other administrative costs must, of course, be figured into the total budget.

5.3.2. Space Requirements and Costs

The source-sampling unit requires office and workshop space. Table 5-3 shows the space requirements of three existing groups and allows approximately 70 square feet of shop area per man. Office space is actually determined by administrative policy, and must be considered on the basis of the number of desks. Minimally, 50 square feet is required for each desk. Private offices require at least 80 square feet. Space costs in leased buildings are on the order of $5 to $6 per square foot per year.

Table 5-3. SPACE REQUIREMENTS FOR SOURCE-SAMPLING PROGRAMS[a]

Agency	Number of personnel[b]	Space allocation, ft^2	
		Workshop	Office
Chicago	5		400
Bay Area	9	625	400
New Jersey	18	1200	360

[a]1969 data.

[b]Does not include clerical or laboratory personnel.

5.4. ADMINISTRATIVE PROCEDURES

5.4.1. Request for Source Test

The source-testing program usually exists as a service to the enforcement, engineering, and permit programs. As such, requests for source tests are initiated outside the unit. As a rule the enforcement section will request a test based on information received from its inspectors. The request may also be motivated by the agency's counsel or by citizen complaints, especially in cases where visual inspection, both inside and outside the plant, reveals no apparent violation. Tests may also be requested to develop emission factors or emission inventories. Often a source test will be requested prior to the issuance of an initial permit to operate.

As programs progress, the members of the source-test unit become more and more knowledgeable of the individual processes. Therefore, as a practical matter, the supervisor of the source-sampling unit will influence the decision to test and the priority of the test. After these decision have been made, the senior engineer takes steps to effect the test and determines the type of testing desired.

The form used for requesting a source test should contain such information as is required to determine test methods, priority, purpose, and status of the action requested. Figure 5-7 shows the type of request form used in Los Angeles. In addition to the basic required information, provisions are made for special instructions to the tester and for determining the status of the test.

Figure 5-8 illustrates an automated form used by the State of New Jersey. This form also identifies the inspector and provides space for his comments. Status of the file can be determined at a glance, and a tickler device has been incorporated.

After the test report has been completed, it should be approved by the agency's chief and submitted to the requester.

SOURCE LOCATION DATA

1. Firm Name _____ Phone No. _____
2. Address _____ City _____
3. Representative to Contact _____ Title _____

REQUEST INITIATION DATA

4. Request Initiated by _____ Division _____
5. Request Approved by _____ Date _____
6. Reason for Request:

☐ Court or Hearing Board Action Case No. _____ ☐ _____

☐ Permit Pending Application No. _____ ☐ _____

☐ Suspected Violation ☐ _____

SOURCE AND SAMPLE DATA

7. Type of Request: ☐ Source Test ☐ Sample Submitted for Analysis
8. Basic Equipment: (incl. Index Code No.) _____
9. Control Equipment: (incl. Index Code No.) _____

_____

10. Points to be Tested or Description and Source of Each Example Submitted:

_____

_____

11. Test for Following Constituents:

_____ _____

_____ _____

12. Special Instructions:

_____

_____

ACTION BY SOURCE TESTING UNIT

13. Date Received _____ Priority _____
14. Date Sent to Analytical Laboratory _____
15. Date Report Issued _____
16. Distribution of Copies _____

REMARKS

_____

Figure 5-7. Source test or sample analysis request form used by Los Angeles Air Pollution Control District.

Figure 5-8. Automated source test request form used by New Jersey Bureau of Air Pollution Control.

6. PRELIMINARY PROCEDURES REQUIRED IN CONDUCTING A STACK TEST

In order to properly plan the stack-testing program, a preliminary survey of the process and test site should be made. Information obtained during this presurvey will help ensure the selection of the proper testing and analytical procedures, and will provide for a more organized test plan.

Except in the most routine cases, an on-site inspection or presurvey will be required to determine certain physical elements that must be known for stack sampling. These elements can be subdivided into process information, test-site location, and emission parameters.

Much of this information can be readily obtained from an on-site inspection. Gas flow rates and compositions can frequently be estimated from process throughputs, emission factors, material balances, and fan and motor type and size. Source registration forms and permit applications will also provide information on the expected emission characteristics.

The use of construction permits for new sources can also ensure the proper location of test ports and necessary scaffolding for future tests.

6.1. PRESURVEY PROCESS INFORMATION

Process information is required in order to determine approximate emission constituents, volumes, and concentrations, as well as to determine the regulation that applies to the particular process being investigated. This information in turn will also have a bearing on both the type of sampling equipment to be used and the sampling schedule.

A successful stack-testing program requires an intimate knowledge of the process to be tested. This can be obtained only by a careful examination of the process and thorough discussions with plant personnel. A single personal contact must be available at the plant. This person must have an understanding of the process and must also have authority to obtain the required information and the cooperation of other plant personnel. A member of the staff of the plant manager or plant engineer is a desirable contact.

Presurveys are greatly facilitated by the use of questionnaires that list the necessary process parameters. Figures 6-1, 6-2, and 6-3 are suggested forms that can be used for presurveys for combustion sources, incinerators, and industrial processes, respectively. These questionnaires are general guides, and in many specific cases additional information will be available. In general, the more preliminary information obtained, the better.

The cyclic operation of a process must also be determined during the presurvey. If a process varies with time over a defined cycle, the variation in emission parameters during the cycle should be investigated. Information must be obtained to decide whether to sample from part of a cycle, a whole cycle, or several cycles. When the process is steady, the desired level of operation must be determined. Any seasonal variation in process conditions should also be obtained.

The exact wording of the applicable regulations may also have a bearing on the desired process operating condition during the proposed tests.

6.2. SELECTION OF TEST SITE

The primary criterion in selecting the test site is that the sample extracted from the site be representative of the main gas stream. Relatively little is known about the disposition of particulates within any specific moving gas stream. Therefore, every effort should be made to obtain a site in which the particulate/gas mixture is as homogeneous as possible. Homogeneity is best achieved in straight vertical ducts. Ideally, the gas flow should not be disturbed by any obstruction or change in direction for approximately 7 to 8 hydraulic diameters* upstream or 2 to 4 diameters downstream from a proposed test location.[3]

---

* Hydraulic diameter = $\frac{\text{area of duct cross section}}{\text{duct perimeter}} \times 4$

Name of Company _____

Address _____

Phone _____ Person to Contact _____

Date of Survey _____ By _____

Entry Requirements _____

Location and Designation of Boiler to be Tested _____

Type of Boiler _____ Capacity, _____ 10^3 lb steam/hr

Type of Fuel _____ Steam Pressure, _____ psig

Btu Value _____ Steam Temperature, _____ °F

Sulfur Content, % by Weight _____

Fuel Composition-Proximate Analysis _____

Fuel Composition-Ultimate Analysis _____

Type and Efficiency of Air Pollution Control Equipment _____

_____

Is Fly Ash Reinjected? _____

Collection Efficiency, % _____

Approximate Opacity of Stack Gases, % _____

Normal Range of Steam Fluctuations _____ To _____

Can Constant Load be Maintained? _____

If So, How Long? _____

Conditions Under Which Boiler can be Tested:

Maximum Steam Load _____

Expected Fuel Rate _____

Can This be Measured? _____

Excess Air Rate _____

Ash Withdrawal Schedule _____

Soot Blowing Schedule _____

Provide complete sketches of entire boiler and flue gas ducting. Indicate proposed locations of test points, sampling port size, location of fans, location of pollution control equipment, obstructions at sampling site, necessary scaffolding, final exit stack dimensions, location of electrical power, and type of sockets.

Figure 6-1. Sample presurvey form for combustion sources.

Name of Company _____

Address _____

Phone _____ Person to Contact _____

Date of Survey _____ By _____

Entry Requirements _____

Location and Name of Unit to be Tested _____

_____

Type of Incinerator _____

Capacity, _____ tons/hr

Type of Air Pollution Control Equipment _____

Collection Efficiency, % _____

Normal Charging Rate _____

How is Charging Rate Measured? _____

Operating Schedule _____

Type and Quantity of Auxiliary Fuel _____

Excess Air Rate _____

Overfire and Underfire Air Rates ___ _____

Temperature of Flue Gases at Proposed Test Points _____

Provide complete sketches of entire incinerator and flue gas ducting. Indicate proposed locations of test points, sampling port size, location of fans, location of pollution control equipment, obstructions at sampling site, necessary scaffolding, final exit stack dimensions, location of required electrical power, and type of socket.

Figure 6-2. Sample presurvey form for incinerators.

Name of Company _____

Address _____

Phone _____ Person to Contact _____

Date of Survey _____ By _____

Entry Requirements _____

Type of Process _____

Location of Process _____

Operating Schedule _____

Process Description _____

Process Feed Rates _____

_____

_____

_____

Expected Emissions

Type	Concentration	Quantity

Type and Efficiency of Air Pollution Control Equipment _____

_____

Opacity of Exit Gases _____

Expected Stack-Gas Parameters at Test Location _____

_____

Temperature, °F _____

Pressure, psig _____

Volume, acfm _____

Composition, % H_2O _____

% N_2 _____

% O_2 _____

_____

_____

_____

Ambient Conditions at Test Site(s) _____

Temperature _____

Noxious Gases _____

Weather Protection _____

Required Safety Gear _____

Provide complete sketches of entire process and exit gas ducting. Indicate proposed locations of test points, sampling port size, location of fans, location of pollution control equipment, obstructions at sampling site, necessary scaffolding, final exit stack dimensions, location of electrical power and water.

Figure 6-3. Sample presurvey form for industrial processes.

In addition to flow considerations, accessibility to the site is an important consideration. Safety, as well as clearance for the probe and sampling apparatus, availability of electricity, weather exposure, and presence of toxic or explosive gases, must all be considered in selecting a site.

Because of these many considerations, compromises must be made in a test site selection. Efforts should be made to obtain ideal flow conditions, however. In some cases, a suitable test site may not be available without major changes in the duct work. If these changes cannot be made, a meaningful sample may not be practical, and only approximate emission results will be obtained.

6.3. PRELIMINARY DETERMINATION OF EMISSION PARAMETERS

In addition to general process-related information, more detailed information regarding the gas stream parameters at the test site is desirable. This is especially true for atypical processes. In many cases, the exit-gas composition, volume, and temperature can be approximated by material-balance calculations, by readings from process instrumentation, or by comparison to similar processes for which data are available. When no data can be obtained, exit-gas parameters may be determined by inserting a probe into the duct at or near the test site. In this manner, an approximate velocity and temperature can be determined. Color-change detection tubes using a squeeze-bulb sampler can be used to determine approximate concentrations of a wide variety of gases.

A list of the more important items required in conducting presurveys includes:

1. 50° to 1200°F dial thermometer (12-inch stem).
2. Velometer.
3. 50-foot tape measure.
4. Set of basic tools.
5. Polaroid camera.
6. Detection tube samplers.
7. Presurvey forms.
8. Safety equipment.

7. PARTICULATE SAMPLING PROCEDURES

The particulate sampling procedure used by the Office of Air and Waste Management of the Environmental Protection Agency utilizes specialized sampling equipment and analytical procedures to obtain both a filterable and a nonfilterable or condensable fraction of particulates. However, all of the material collected may not be used in determining compliance with an emission regulation. This depends on the regulation and associated test specification. Special procedures are also used to ensure maintenance of isokinetic sampling rates.

7.1. MEASUREMENT OF STACK GAS VELOCITY AND RELATED PARAMETERS[4,5]

Prior to performing any particulate measurements, the sampling team must determine the velocity of the gas flowing through the duct at the test location. This velocity determination is very important and is composed of a number of mathematically related parameters, as shown in Equation 7-1. Not only is the total gas flow determined from this velocity measurement, but the sampling rates are also based on this value.

$$V_s = KC_p \sqrt{\frac{T_s \Delta p}{P_s M_s}} \qquad (7\text{-}1)$$

where:

V_s = stack-gas velocity
T_s = temperature
Δp = velocity head
P_s = stack-gas pressure
M_s = stack-gas molecular weight
C_p = pitot tube coefficient
K = constant depending on units used

7.1.1. Location of Traverse Points

Because the velocity through any cross-sectional plane area perpendicular to the flow direction is not uniform, the area must be divided into a number of equal-sized subareas. The various parameters that affect velocity should then be determined at the centroid of each of these areas. The average velocity is determined by taking the arithmetic average of the individual velocities, namely:

$$V_s = \left(\sum_{i=1}^{N} V_{si} \right) / N \qquad (7\text{-}2)$$

where:

V_s = average velocity
V_{si} = average velocity in any subarea
N = number of test points

The number of subareas required to obtain a reliable average velocity varies with the test site conditions. When the test site is at least 8 hydraulic diameters downstream or 2 diameters upstream of any flow disturbances, 12 test points should be used for stack diameters of 2 feet and greater. When the diameter is less than 2 feet, 8 test points should be used. When these conditions cannot be met, Figure 7-1 should be used to determine the number of required points. Sampling sites less than 2 diameters downstream or 0.5 diameter upstream from a flow disturbance should be avoided if possible.

In circular ducts, the cross-sectional area is subdivided into concentric areas, and measurements are made at four locations in each area, as shown in Figure 7-2. The distances to these points, which are located along the centroid of the areas, are calculated by Equation 7-3.

$$Pj = 50 \left[1 - \sqrt{\frac{(2j-1)}{2a}} \right] \qquad (7\text{-}3)$$

where:

Pj = percent of diameter from inside of duct wall to measurement point
a = total number of areas selected = N/4
j = number of area being calculated, such as 1, 2, 3, 4.....numbered from the center outward

Equation 7-3 provides only half of the distances needed. The remaining distances are obtained by calculating the difference between each calculated percentage and 100. Table 7-I presents the percentages determined from Equation 7-3 for up to 12 areas.

For rectangular ducts, the area should be divided into approximately square subareas as shown in Figure 7-3. Measurements are made at the center of each subarea.

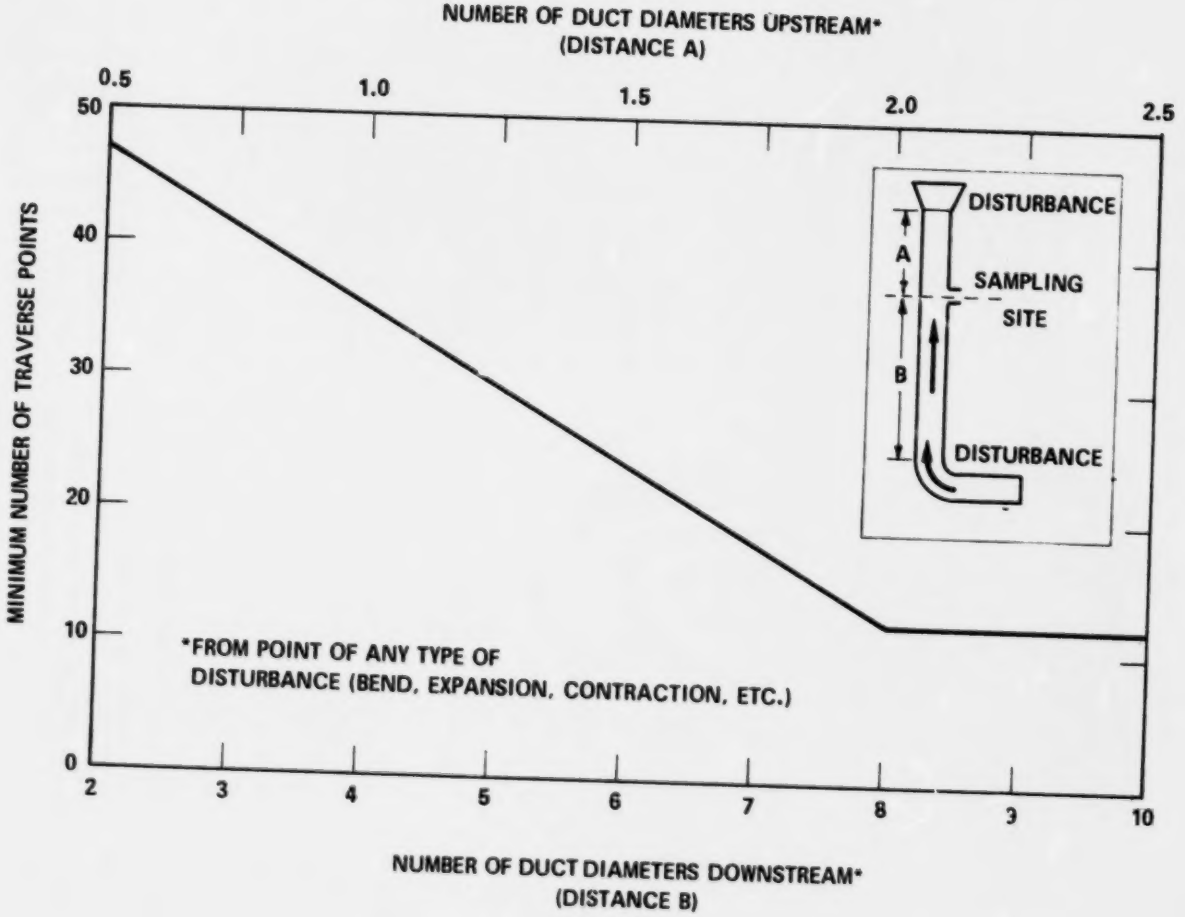


Figure 7-1. Minimum number of traverse points.[6]

▲ INDICATES SAMPLING POINT

$D_1 = P_1 \times D_S$

$D_2 = P_2 \times D_S$

WHERE: $P_{1,2}$ IS DETERMINED FROM EQUATION 7-3 OR TABLE 7-1

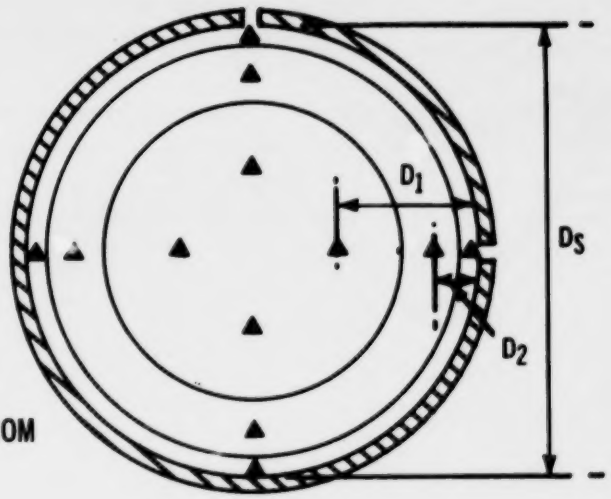


Figure 7-2. Cross section of circular flue divided into three concentric equal areas, showing location of sampling points.

WHERE:

d_1 = NUMBER OF AREAS ACROSS FLUE WIDTH

d_2 = NUMBER OF AREAS ACROSS FLUE PERPENDICULAR TO WIDTH.

AND $0.5 \leq \left(\frac{D_1}{d_1} \div \frac{D_2}{d_2} \right) \leq 2$

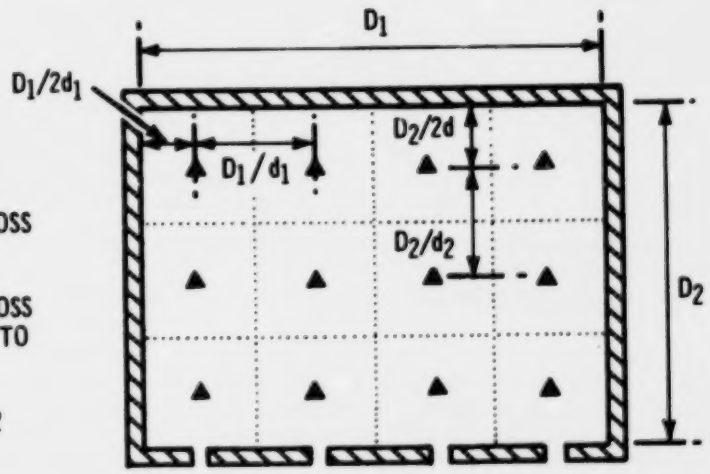


Figure 7-3. Cross section of rectangular flue divided into twelve equal areas with sampling points located at the center of each area.

Table 7-1. PERCENT OF CIRCULAR STACK DIAMETER FROM INSIDE WALL TO TRAVERSE POINT

Traverse point number along diameter[a]	Number of traverse points on single diameter[b]									
	6	8	10	12	14	16	18	20	22	24
1	4.4	3.3	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	14.7	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3	29.5	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4	70.5	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5	85.3	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6	95.6	80.6	65.8	35.5	26.9	22.0	18.8	16.5	14.6	13.2
7		89.5	77.4	64.5	36.6	28.3	23.6	20.4	18.0	16.1
8		96.7	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9			91.8	82.3	73.1	62.5	38.2	30.6	26.1	23.0
10			97.5	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11				93.3	85.4	78.0	70.4	61.2	39.3	32.3
12				97.9	90.1	83.1	76.4	69.4	60.7	39.8
13					94.3	87.5	81.2	75.0	68.5	60.2
14					98.2	91.5	85.4	79.6	73.9	67.7
15						95.1	89.1	83.5	78.2	72.8
16						98.4	92.5	87.1	82.0	77.0
17							95.6	90.3	85.4	80.6
18							98.6	93.3	88.4	83.9
19								96.1	91.3	86.8
20								98.7	94.0	89.5
21									96.5	92.1
22									98.9	94.5
23										96.8
24										98.9

[a]Points numbered from outside wall toward opposite wall.

[b]The total number of points along two diameters would be twice the number of points along a single diameter.

7.1.2. Velocity Head Measurements

A pitot tube and inclined manometer are commonly used to measure velocities equivalent to at least 400 feet per minute at 60°F. A Stauscheibe, or type-S, pitot tube is recommended for velocity head measurements. This instrument is shown in Figure 7-4.

When using the type-S pitot tube, a correction factor must be applied to the velocity head readings. This factor is usually about 0.85, but can vary between 0.8 and 0.9, depending on the exact configuration of the openings. This correction factor should be checked by comparing velocity head readings taken at a point of constant air flow with a standard pitot tube, which is also shown in Figure 7-4. The correction factor is the ratio of the square root of the velocity head reading obtained with the standard pitot tube* to the square root of the reading obtained with the type-S pitot tube. A sample calibration calculation is shown in Table 7-2.

The velocity head is the arithmetic difference between the total pressure and the static pressure in the duct. This difference in pressures is read on an inclined manometer by connecting the two leads on the pitot tube to the two ends of the inclined manometer with flexible tubing (¼-inch-O.D. rubber and Tygon have both proved adequate). The impact or upstream leg of the pitot tube measures the total pressure and is connected to the zero end of the inclined manometer. The other leg of the pitot tube, used to measure static pressure, is connected to the manometer's high side.

* The correction factor for the standard pitot tube is approximately 1.0; its actual value, which could vary from 0.98 to 1.02, should be determined by the manufacturer.

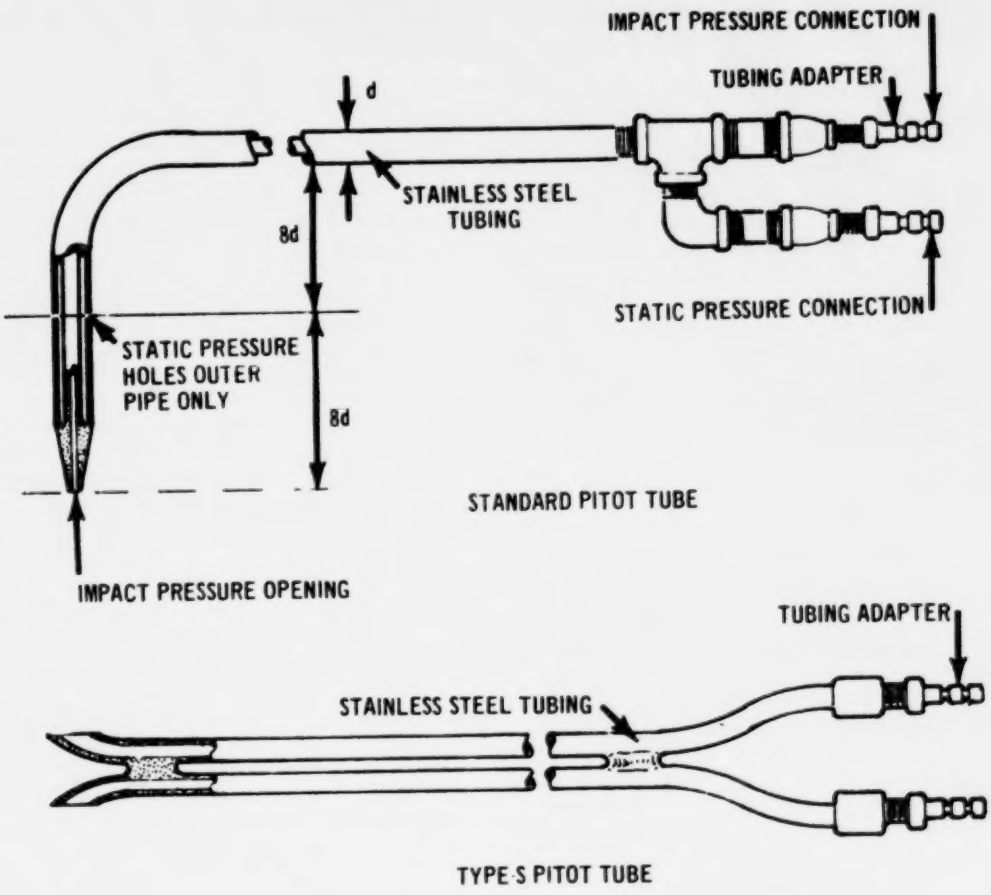


Figure 7-4. Typical pitot tubes used to measure velocity head.

Table 7-2. EXAMPLE DETERMINATION OF TYPE-S PITOT TUBE CORRECTION FACTOR

Standard pitot reading		Type-S pitot reading		
H_o	$\sqrt{H_o}$	H_1	$\sqrt{H_1}$	$\frac{\sqrt{H_o}}{\sqrt{H_1}} = C_p$
0.3	0.5477	0.415	0.642	0.853
0.5	0.7071	0.700	0.837	0.844
1.0	1.000	1.44	1.200	0.833
				C_p=0.843

Any suitable manometer may be used to read the velocity head. The accuracy of the velocity determination, however, depends on the accuracy of the readings obtained. Because the velocity readings are the single most important factor leading to errors in source-sampling work, a sensitive, easily read instrument must be used. A manometer that can be read to within 1 percent of the highest expected reading is desirable.

Actual velocity head readings should not be taken until the process has been operating at the desired conditions for at least 30 minutes. During this period the distances to the required measurement points can be calculated, and the pitot tube can be marked. Marking can be done with a high-temperature crayon or masking tape. If the duct has a thick wall, or if a pipe fitting protrudes from the wall, this dimension must be added to the distances calculated from the duct's inside wall to the test points.

Before and during the velocity traverse, the following precautions should be taken:

1. The manometer connections and tubing should be checked for leaks, kinks, or foreign matter. (See Section 7.4.2.3)

2. The manometer should be carefully leveled, and the liquid column should be set exactly on zero. This should be done after the pitot tube has been connected in order to avoid disturbing the manometer. To prevent any air movement from affecting the zero setting, a cloth should be held over the end of the pitot tube. The zero setting and level of the manometer should be checked during the test work.

3. The pitot tube must be held at right angles to the gas flow, and the impact opening of the tube must point directly into the gas stream. It should be noted that the maximum reading for a type-S pitot tube does not occur when the pitot tube is properly aligned at right angles to the direction of gas flow.

4. The test ports should be kept sealed to prevent air flow from affecting the readings.

5. In ducts where erratic velocity head readings are taken (a common occurrence), an average value must be taken by visual observation. In taking a visual average reading, try to ignore the rapid extreme fluctuations in pressure. Glass capillary tubes inserted in the pitot tube connecting lines will dampen out some fluctuations.

6. Take readings at the designated subarea centers only, and not at the duct edges or center.

Always use a standardized form to record velocity head readings and other pertinent test data. A suggested form is shown in Figure 7-5. Any readings that appear to be unusually high or low should be rechecked immediately.

For very low velocity measurements, a hot-wire anemometer or vane-type anemometer may be tried. These devices must be calibrated at the temperature at which they are to be used; also, they do not give accurate readings if particulates are allowed to deposit on them. If the latter occurs, the flow must be estimated based on material balance and/or fan data.

7.1.3. Temperature and Static-Pressure Measurements

A long (36-inch) stem dial thermometer with a range of 50° to 750°F will provide the best overall temperature measurements in ducts up to about 40 square feet in area. Though temperatures are usually fairly uniform across any cross-sectional area, a traverse with the thermometer should be made to check uniformity.

For larger ducts and for high temperatures, a thermocouple and potentiometer will be required to measure temperatures. In such cases, the temperature readings should be taken at the same points and preferably at the same time that the velocity head readings are made. For temperatures in excess of approximately 750°F, a shielded thermocouple should be used. When temperature variations occur, a continuous recording of the thermocouple readings will be useful to define the cyclic nature of the process.

All temperature data, including identification of the instrument used, should be recorded on the velocity traverse data sheet (Figure 7-5).

Approximate static-pressure measurements in the duct may be made by connecting one leg of a type-S pitot tube to a vertical U-tube manometer containing either water or mercury, depending on the expected range of pressure, and turning the pitot tube sideways in the duct. The other leg of the manometer is open to the atmosphere. This static gauge pressure may be either a positive (pressure) or a negative (vacuum) reading. It should be determined to the nearest 0.1 inch of water.* The absolute pressure in the duct is obtained by adding the value for static gauge pressure to the atmospheric (barometric) pressure at the test location (add the value for gases under pressure and subtract for vacuum readings). Equation 7-4 illustrates this calculation.

The atmospheric pressure is determined with an aneroid barometer or, if available, a Fortin mercury-in-glass barometer. The aneroid barometer should be checked and calibrated with a Fortin barometer. Temperature corrections must be applied to the Fortin barometer when the ambient temperature is not 32°F.†

* Because this measurement is not critical to the velocity determination, it may be ignored if it is less than approximately 15 inches of water. This measurement is frequently useful from a process or equipment standpoint, however.

† Temperature corrections and other useful data are contained in ASME PTC 19.2 — 1964 — Pressure Measurement

Test No. _____

Location _____

VELOCITY TRAVERSE DATA

Point	Position, inches[a]	Reading, Δp inches of H_2O	$\sqrt{\Delta p}$	T_s, °F
Total		_____		
Average		_____		

[a] From outside of port to sampling point.

Pitot tube _____
Manometer _____
Thermometer _____

Stack Inside Dimensions _____

Stack Area = _____ ft^2

Barometric Pressure, P_b = _____ inches Hg, stack gauge

Pressure = _____ inches H_2O

Stack Abs. Pressure, P_s = _____ inches $\frac{H_2O}{13.6}$ + P_b = _____ inches Hg

Stack Gas Temp., T_s = _____ °F. + 460 = _____ °R

Molecular Weight of Stack Gas, M_s = _____

1. $V_s = 174\ C_p \sqrt{\Delta p T_s} \times \frac{29.92}{P_s} \times \frac{28.96}{M_s}$

   V_s = _____ ft/min

2. Volume = _____ ft/min x _____ ft^2 = _____ ft^3/min

   Standard Volume at 70°F and 29.92 inches Hg:

3. $ft^3/min \times \frac{530}{T_s} \times \frac{P_s}{29.92}$ = _____ x $\frac{530}{\text{_____}}$ x $\frac{\text{_____}}{29.92}$ =

   _____ scfm

Data Recorder _____

Date _____

Figure 7-5. Gas velocity and volume data.

$$P_s = P_b + \frac{\pm p_s}{13.6} \qquad (7\text{-}4)$$

where:

P_s = absolute pressure in stack, inches of mercury

P_b = atmospheric pressure at test site, inches of mercury, measured with a barometer

P_s = stack gas gauge pressure, inches of water

7.1.4. Gas Density and Moisture Determinations

7.1.4.1. Gas Density

In addition to temperature and pressure, composition also influences the density of stack gases. Although many exit-gas compositions are similar to that of air, it may not be valid to assume that such a similarity exists for various chemical compositions; a chemical analysis will thus be required. For example, gas streams from a chlorine plant may contain high concentrations of chlorine, which has a molecular weight of 71. Since the molecular weight of air, upon which the velocity equations are based, is 28.96, a large difference in gas densities could lead to an error in the velocity determination.

For most combustion gases, the density is fairly close to that of air, and if no correction is applied, only a small error will result. The density may be checked, however, with an Orsat analysis and the following calculation procedure:

(Percent CO_2 by volume, dry basis) x 0.44 = ——
(Percent CO by volume, dry basis) x 0.28 = ——
(Percent O_2 by volume, dry basis) x 0.32 = ——
(Percent N_2 by volume, dry basis) x 0.28 = ——

$\Sigma = M_d$ = ——

$$M_s = M_d \left(\frac{100 - W}{100}\right) + 0.18W \qquad (7\text{-}5)$$

where percent CO_2, CO, and O_2 are measured by the Orsat apparatus, and percent $N_2 = 100 - (\%CO_2 + \%CO + \%O_2)$,

M_d = average molecular weight, dry basis

W = volume percent moisture in flue gas (Equation 7-6)

M_s = average molecular weight of actual flue gas

7.1.4.2. Moisture Content

Moisture content can be determined more accurately after a particulate sample has been taken, because the train used to collect particulates will also collect moisture. A preliminary estimate of moisture content, however, can be obtained through a knowledge of the process, with a material balance, from wet and dry bulb readings, by passing a measured quantity of gas through an accurately weighed desiccant, or by condensation techniques.

Passing a measured volume of stack gas through a container with an accurately weighed quantity of silica gel has been used to determine moisture content. In this case the quantity of moisture collected, divided by the sample volume, will yield the percent moisture as shown in Equation 7-6. Care must be taken not to saturate the silica gel and to provide sufficent contact time for water vapor absorption.

$$W = \frac{V_{w1}}{V_m + V_{w1}} \times 100 \qquad (7\text{-}6)$$

V_{w1} = (weight gain of silica gel, grams) x 0.0474*

where:

V_m = metered volume of dry gas at 70°F and 29.92 inches Hg

W = % moisture in stack gas by volume

V_{w1} = ft^3 of moisture collected at 70°F and 29.92 inches Hg

When the full particulate sampling train is used as described in Section 7.4, moisture will be condensed in the impingers and also absorbed by the silica gel; this quantity must be included in the total moisture calculation. Thus, if V_{w2} = (moisture condensed out in impingers, ml) x 0.0474, then:

$$W = \frac{V_{w1} + V_{w2}}{V_m + V_{w1} + V_{w2}} \times 100 \qquad (7\text{-}7)$$

* Cubic feet of equivalent vapor occupied by 1 gram of water at 70°F and 29.92 inches Hg.

7.1.5. Calculation of Velocity and Total Gas Flow

Calculation of stack gas velocity is not required prior to sampling if the recommended sampling method is used. The average velocity head and other stack gas parameters, however, are required. If needed, the velocity may be calculated according to Equations 7-8 and 7-9.

$$V_s = \left(\sum_{i=1}^{N} V_{si} \right) / N \qquad (7\text{-}8)$$

$$V_{si} = K C_p \sqrt{\Delta p T_{si} \times \frac{28.96}{M_s} \times \frac{29.92}{P_s}} \qquad (7\text{-}9)$$

where:

V_{si}	=	stack gas velocity at point i, feet per minute
C_p	=	pitot tube correction factor (dimensionless)
Δp	=	velocity head, inches of water
T_{si}	=	stack gas temperature at point i, °R
M_s	=	stack gas molecular weight
P_s	=	stack gas absolute pressure, inches of mercury
N	=	number of sampling points
K	=	174 when units listed above are used

If the molecular weight of the gas is similar to that of air, and the stack pressure is approximately 29.92, Equation 7-9 simplifies to:

$$V_{s_i} = 174\, C_p \sqrt{\Delta p\ T_{si}} \qquad (7\text{-}10)$$

The average velocity is then the arithmetic average of all the V_{s_i}. If the temperature is ±0.5 percent (absolute) throughout the duct cross section, the average velocity in the duct is obtained by:

$$V_s = 174\ C_p \sqrt{\Delta p}\ \times (\text{avg. } \sqrt{T_s}). \qquad (7\text{-}11)$$

Figure 7-5 (the velocity data sheet) provides a convenient form for computing velocity and total gas volume in a duct.

7.2. DETERMINATION OF ISOKINETIC SAMPLING RATES

During isokinetic sampling, the velocity of the gas entering the sampling nozzle is identical to the velocity in the duct at the sampling point. In most gas streams, isokinetic sampling is required to prevent segregation of the particulate matter and, consequently, a biased sample.

Isokinetic sampling rates may be calculated if the gas velocity, temperature, pressure, nozzle area, and gas metering conditions are known. These variables are related as shown in Equation 7-12.

$$Q_{m_i} = V_{s_i} A_n \frac{T_m}{T_{s_i}} \times \frac{P_s}{P_m} \times \left(\frac{100\text{-}W}{100} \right) \qquad (7\text{-}12)$$

where:

Q_{m_i}	=	sampling rate at meter conditions at point i, ft^3/min
V_{s_i}	=	stack gas velocity at point i, feet/min. (Equation 7-9)
A_n	=	nozzle area, ft^2
T_m	=	average temperature of gas passing through dry gas meter, °R
T_{s_i}	=	average temperature of stack gas at point i, °R
P_s	=	average absolute pressure of stack gas, in. of Hg
W	=	moisture in stack gas, % (Equation 7-6 to 7-7)

The basic orifice flow rate equation is:

$$Q_m = K_m \sqrt{\frac{\Delta H T_m}{P_m M_s}} \qquad (7\text{-}13)$$

where:

Q_m	=	meter flow rate, ft^3/min
K_m	=	orifice calibration constant, includes orifice coefficient and unit conversions
ΔH	=	pressure drop across orifice, inches of water

This relationship is obtained by calibrating the orifice and plotting the values of Q_m versus ΔH on log-log graph paper.

When using the procedures described herein, an orifice with a pressure drop of approximately 1.84 inches of water at a flow of 0.75 ft^3/min is recommended.

The basic isokinetic flow rate equation was given in Equation 7-12 as:

$$Q_m = V_s A_n \frac{T_m}{T_s} x \frac{P_s}{P_m} x \frac{100\text{-}W}{100} \qquad (7\text{-}12)$$

V_s, however, was given by Equation 7-9 as:

$$V_s = 174\, C_p \sqrt{\Delta P\, T_s \times \frac{28.96}{M_s} x \frac{29.92}{P_s}} \qquad (7\text{-}9)$$

Substituting Equation 7-9 into 7-12 gives:

$$Q_m = 174\, C_p \sqrt{\Delta P T_s C_1} \times A_n \frac{T_m}{T_s} x \frac{P_s}{P_m} x \frac{100\text{-}W}{100} \qquad (7\text{-}14)$$

where:

$$C_1 = \frac{28.96}{M_s} x \frac{29.92}{P_s}$$

To determine the nozzle size, a sampling rate of 0.75 ft^3/min* is substituted for Q_m and Equation 7-12 is rearranged and solved for A_n, the nozzle area (Equation 7-15). An available nozzle size approximating the value calculated is then used to calculate the actual sampling rates at the individual traverse points.

$$A_n = \frac{Q_m}{V_s} x \frac{T_s}{T_m} x \frac{P_m}{P_s} x \frac{100}{100\text{-}W} \qquad (7\text{-}15)$$

7.2.1. Calculation Aides.

Because a separate calculation is required for every traverse point, the determination of isokinetic sampling rates can be quite laborious, especially if stack-gas flow conditions vary with time. Various aids that have been developed to assist in this calculation, if properly used, will reduce computational errors and time, and provide a more reliable procedure for obtaining isokinetic rates.

A straight-line relationship exists between the velocity head measurement (Δp) and the pressure drop (ΔH) across the orifice flow rate meter used in the sampling train. This relationship, along with the related variables, has been plotted on nomographs as shown in Figures 7-6 and 7-7.

Variations in the assumptions used in preparing the operating nomograph (Figure 7-7) are compensated for by the auxiliary correction nomograph shown in Figure 7-6. The only variable not taken into account is the dry molecular weight of the stack gas, which is assumed to be approximately equal to that of air.

The following example illustrates the procedure for using the correction nomograph and the operating nomograph with these assumed conditions:

Orifice pressure drop
ΔH @ 0.75 ft^3/min = 2.7 in. H_2O from orifice calibration (Appendix C)

P_s	= P_m = 29.9 in. Hg
T_s	= 600°F
T_m	= 100°F
W	= 20% H_2O
Avg. Δ_p	= 0.36 in. H_2O

Figure 7-6 contains instructions for obtaining the correction factor C. With the correction factor determined, the sliding portion of the operating nomograph is placed so that C is set opposite the reference mark as shown in Figure 7-7. The K factor must now be determined on the operating nomograph. This point will then be the pivot point, which must be on the straight line connecting Δp and the desired ΔH.

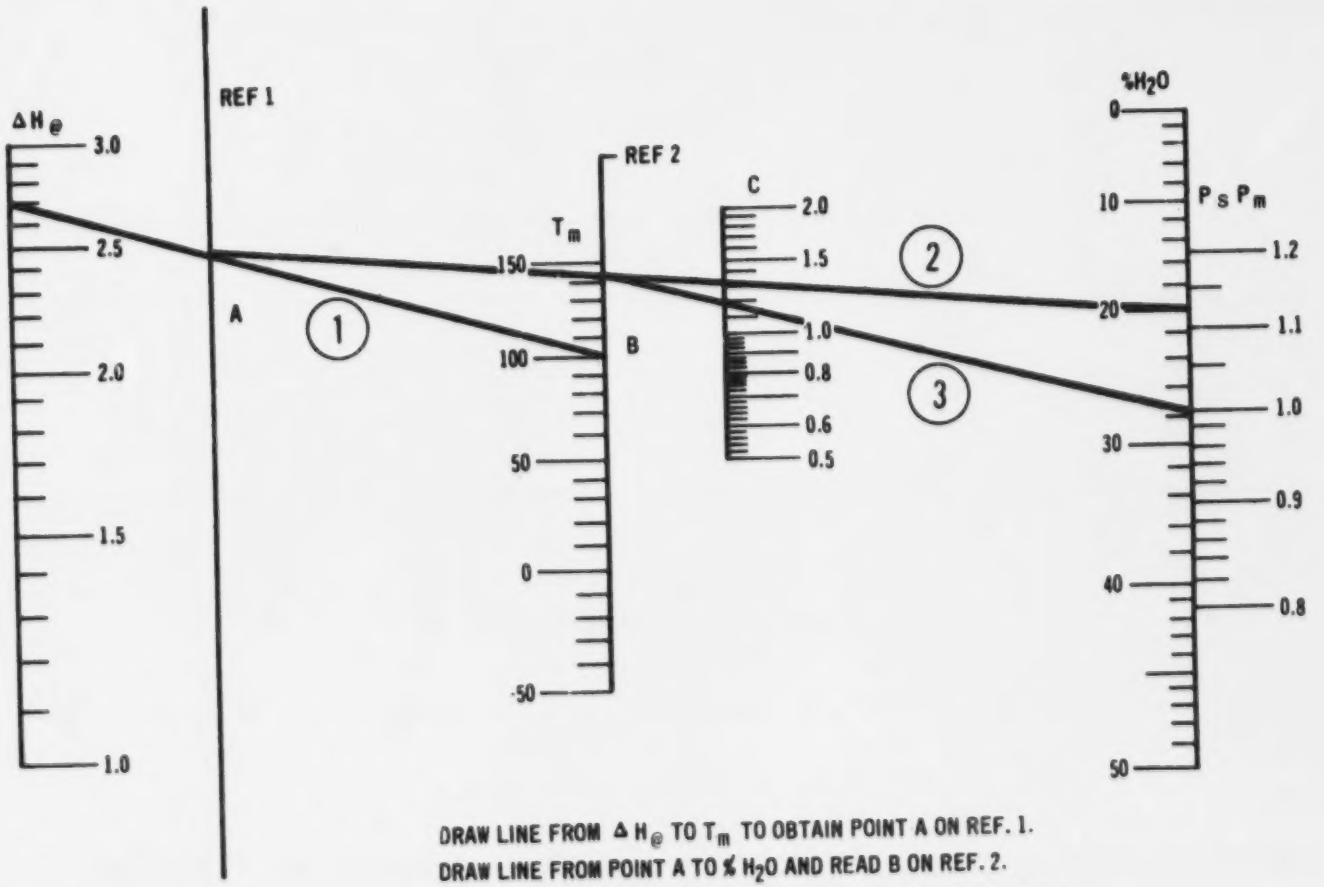
Figure 7-7 illustrates this procedure.

1. Connect stack temperature to average pitot reading Δp.
2. Select a probe-tip diameter as close as possible to that indicated in Step 1. (In this example use ¼ inch.)
3. Align the actual probe-tip diameter with the stack gas temperature to determine an artificial pitot reading.
4. Align the artificial pitot reading with the reference mark on the ΔH axis.
5. This line crosses the K axis at the desired K pivot point.

During sampling, ΔH is determined by connecting the observed pitot reading, through K, to the ΔH scale. As long as the meter and stack-gas parameters do not change very much, this K factor remains constant. If large changes are noted, a new C and K must be determined.

Unmarked copies of these two nomographs are provided in Appendix A for the reader's use.

* Any desired sampling rate may be used. With the equipment described here, a rate of 0.75 ft^3/min is recommended.



DRAW LINE FROM $\Delta H_@$ TO T_m TO OBTAIN POINT A ON REF. 1.
DRAW LINE FROM POINT A TO % H_2O AND READ B ON REF. 2.
DRAW LINE FROM POINT B TO P_s/P_m, AND OBTAIN ANSWER FOR C.

Figure 7-6. Correction factor nomograph.[7]

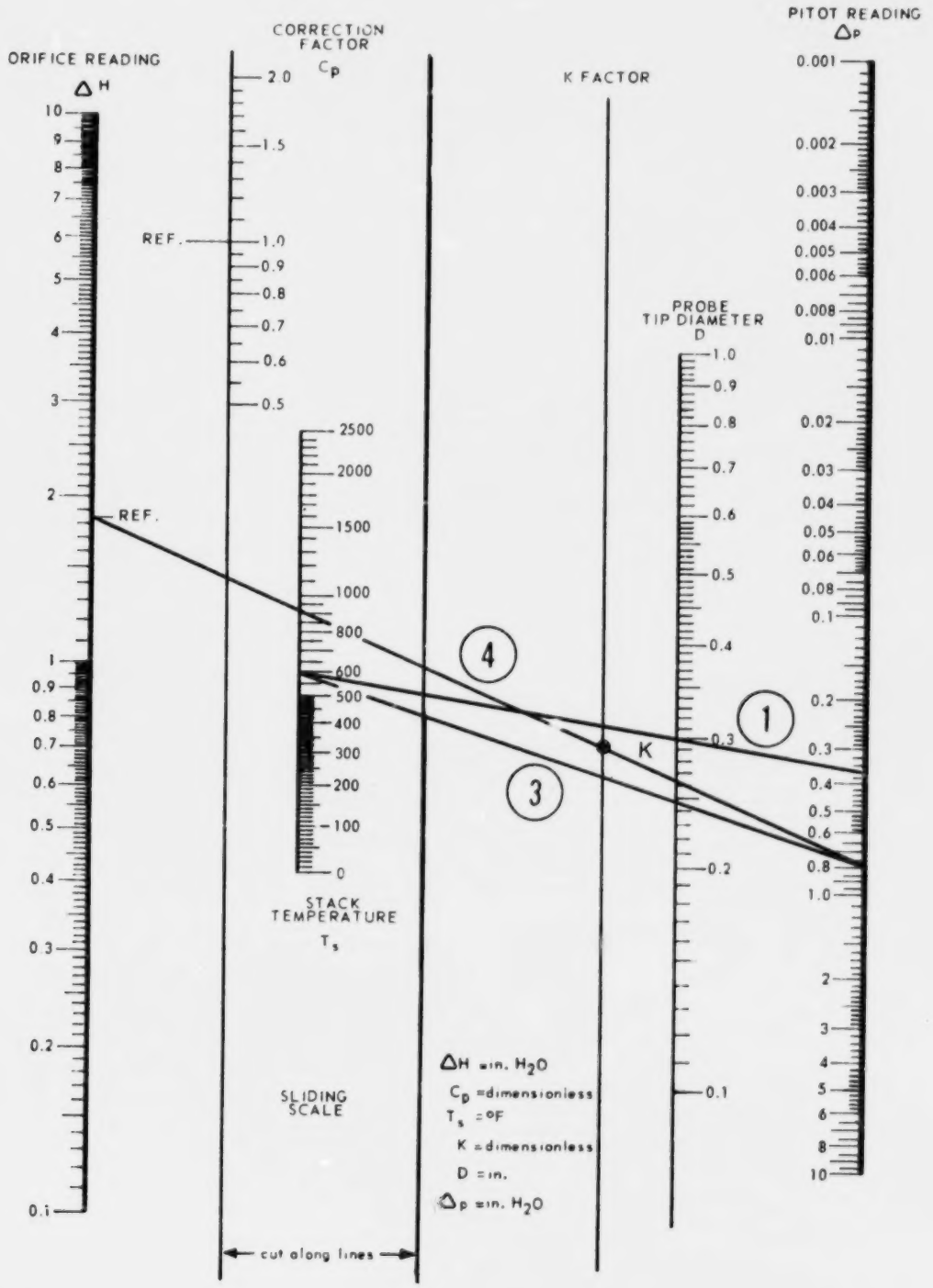


Figure 7-7. Operating nomograph.[7]

7.3 NONIDEAL SAMPLING CONDITIONS

In practice, nonideal sampling conditions are frequently encountered because of nonuniform flow distributions and/or flow variations with time. Nonuniform flow patterns are caused by obstructions to the flow caused by fans, bends, dust collectors, duct transitions, etc. Cyclic conditions can be attributed to the operation of the process. The degree of nonuniformity of flow, though usually evident from the configuration of the duct, can only be determined by making a traverse of the duct with the pitot tube as discussed in Section 7.1.1.

7.3.1. Poor Flow Distribution

When sampling less than 8 hydraulic diameters downstream or less than 2 diameters upstream from a flow disturbance, the number of sampling points should be increased in accordance with the procedures in Section 7.1.1. Sampling errors will be reduced if a greater number of subareas are used to determine average emissions. When the flow pattern is tangential or spiral in nature, only approximate results will be obtained, and modification of the existing duct work should be considered.

7.3.2. Nonisokinetic Sampling Conditions

If isokinetic sampling conditions cannot be maintained because of stack-gas-flow variations or sampling-train problems, a certain error in particulate measurement may occur. The degree of error will depend on the departure from isokinetic conditions and on the particle size. Figure 7-8 presents experimental data on the expected range of error. Further work, however, is still required to quantify the magnitude of these errors. In the interim, one can only try to achieve isokinetic sampling rates as closely as possible.

Particulate concentrations and emissions are usually determined by computing the concentration of particulates and multiplying by the volume of gas emitted (Section 7.8). Emissions may also be computed by determining the emission rate per unit time (pounds per minute) and multiplying this ratio by the ratio of stack area divided by sampling nozzle area. By calculating the mass emission rate by these two methods and comparing the results, the ratio of isokinetic rate actually achieved may be determined. The two methods yield identical results under exact isokinetic sampling conditions. By selecting one calculation method or the other, or by averaging the two, more accurate emission data can be obtained.[9]

7.3.3. Cyclic Flow Conditions[10]

When gas flows and emissions vary with time each point should be sampled for a complete cycle For long cyclic periods, each point may be sampled for a 3- to 5-minute period, and the entire duct should be traversed two to three times. At times, exit-gas particulate concentrations and flows will be nonuniform and unsteady. This presents a difficult sampling condition since the duct should be traversed and each sample should extend over a whole cycle or specified number of cycles. For large ducts, or when long cycles are encountered, the total sampling time can become very long. The use of a number of sampling trains operating simultaneously will reduce total sampling time.

7.4. PARTICULATE SAMPLING EQUIPMENT

A wide variety of sampling trains is available for determining particulate emissions. These trains have been described in the literature, and each has its particular advantages and disadvantages depending on the sampling conditions and the object of the test.[4,5,11] In all cases, however, the trains consist of a carefully sized sampling nozzle or probe tip, a probe to convey the gases, a filter or particulate/gas separating device, a pump, and a gas meter. When hot gases (greater than approximately 150°F) are sampled, a condenser or similar cooling device is also used to protect the pump and meter.

7.4.1 Description of Sampling Train[7, 12]

The particulate sampling train recommended and used by the Office of Air and Waste Management is designed to measure both filterable particulate and nonfilterable or condensable matter. Depending on the requirements of a specific emission regulation and the prescribed test procedure, all or only part of the material collected in various parts of the sampling train may be used in calculating emissions to compare with the regulation. The sampling apparatus consists of a removable probe tip, a heated probe, cyclone (optional), heated filter, four impingers connected in series, airtight vacuum pump, dry gas meter, and an orifice flow meter as shown in Figure 7-9. The cyclone is optional because it is only used for expected high grain loadings of particles greater than approximately 5 microns in size. This train is designed for high particulate-collection efficiency and for ease in maintaining isokinetic sampling rates.

Particulate matter is collected on a filter maintained at a temperature of approximately 250°F, and additional matter is collected in the cooled impingers, which operate in the range of 50°to 70°F. Thus, both filterable and nonfilterable fractions of particulate matter are obtained. The use of a filter outside the stack requires heating of the probe and filter to

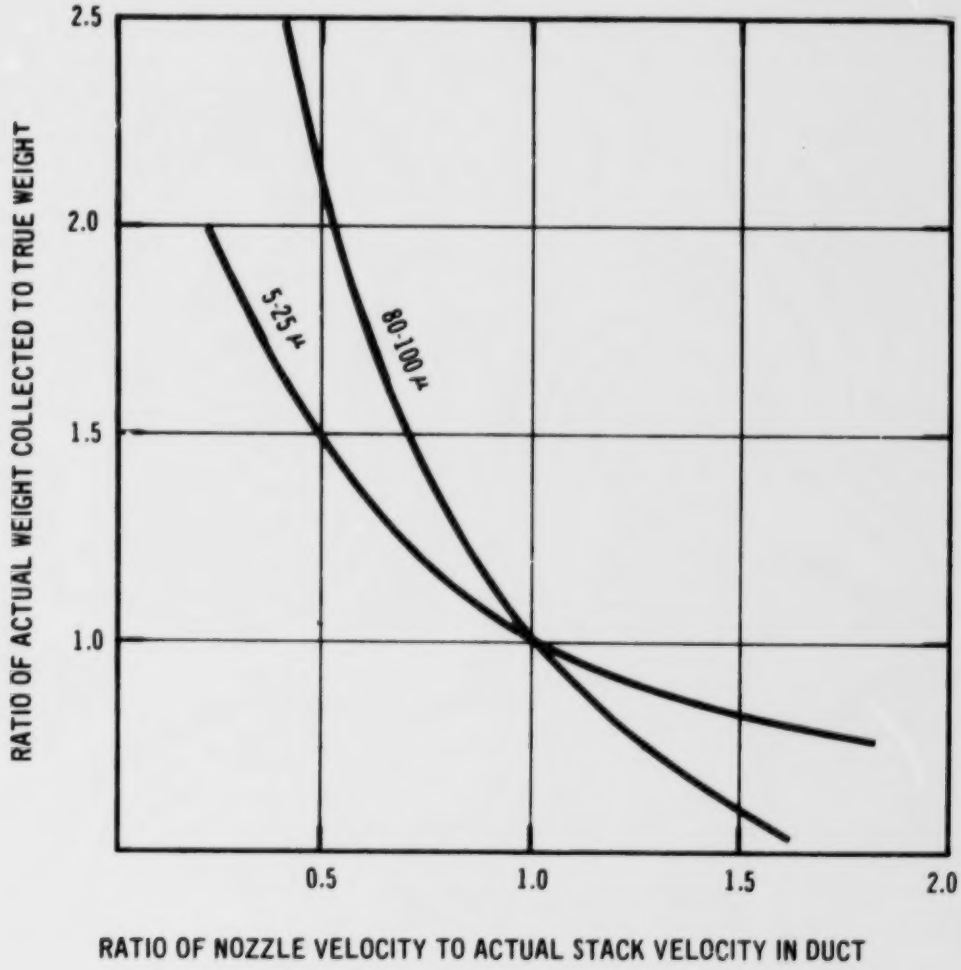


Figure 7-8. Expected errors incurred by non-isokinetic sampling.[8]

Because a wide variety of particle sizes is usually present, these data should not be used to correct concentrations obtained under non-isokinetic conditions.

prevent condensation on the filter and subsequent high-pressure drop. The use of an air-tight vacuum pump in front of the flow meter simplifies the calculations needed to determine and maintain isokinetic flow rates.

As shown in Figure 7-9, the train consists of a button-hook-type nozzle or probe tip that is connected with a coupling to the probe sheath. A glass probe is inside the metal sheath.

The probe connects to a cyclone and flask (optional) when used in the train. The cyclone connects to a coarse, fritted glass filter holder, which holds a tared glass fiber filter.* Commonly used filters range from 2.5 to 4 inches in diameter. When the cyclone is not used, the probe connects directly to the filter holder through an adapter tube. The cyclone, flask, and filter are contained in an electrically heated, enclosed, and insulated box, which is thermostatically maintained at a minimum temperature of 250°F to prevent water condensation. Attached to the heated

* MSA type 1106 BH or equivalent.

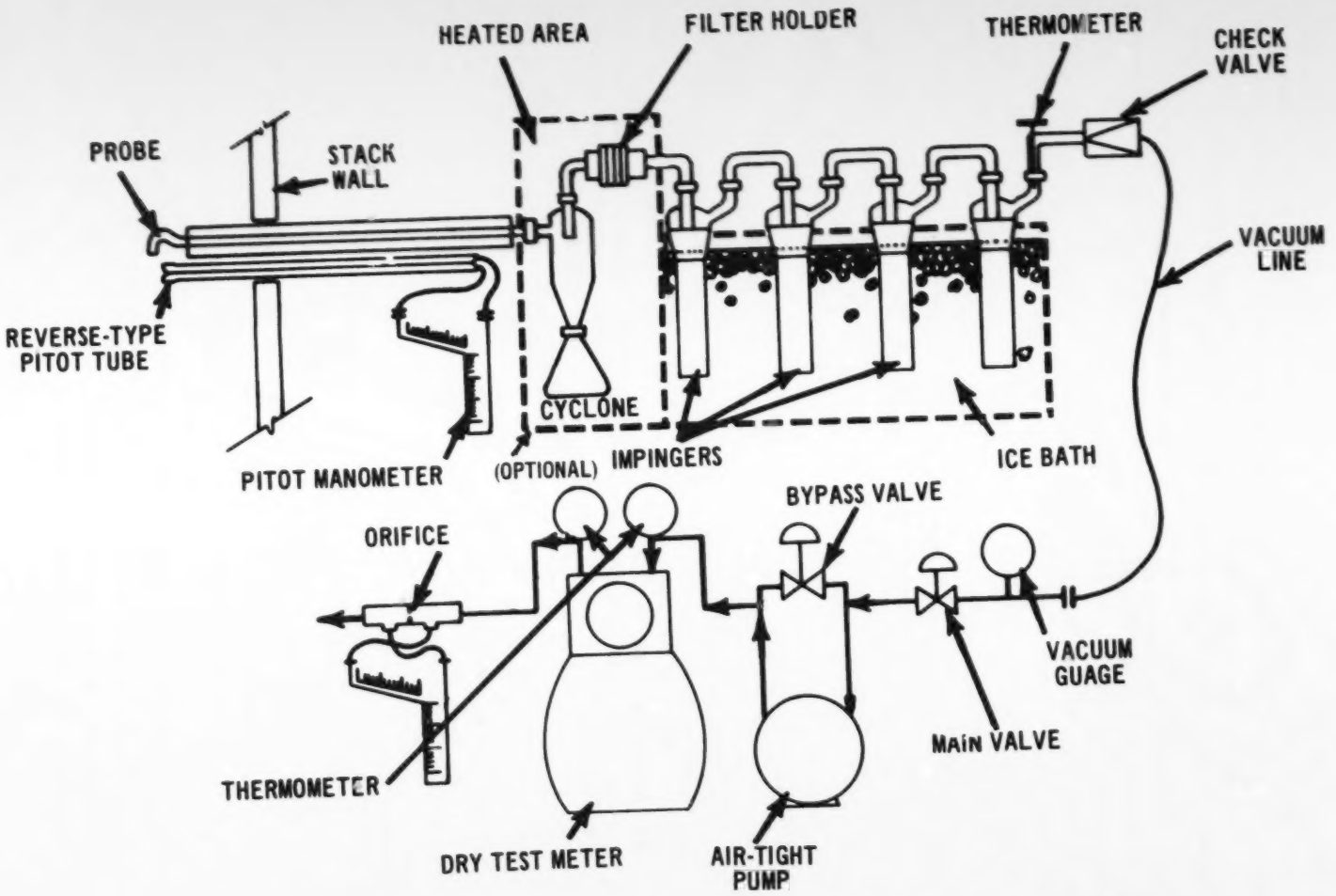


Figure 7-9. Particulate sampling train used by Office of Air and Waste Management[7,12]

box is the ice-water bath containing four impingers connected in series with glass ball and socket joints. The first impinger receives the gas stream from the filter. This impinger – of the Greenburg-Smith design – is modified by replacing the tip with a 0.5-inch-ID glass tube extending to 0.5-inch from the bottom of the flask. This impinger is initially filled with distilled deionized water.* The second impinger is a standard Greenburg-Smith impinger with tip that is also filled with distilled deionized water. The third impinger is a dry Greenburg-Smith impinger modified like the first, and contains approximately 200 grams of accurately weighted dry silica gel.

From the fourth impinger the sampled gas flows through a check valve; flexible rubber vacuum tubing; vacuum gauge; a needle valve; an airtight vacuum pump rated at 4 cubic feet per minute at zero inches of mercury gauge pressure, and connected in parallel with a bypass valve; and a dry gas meter rated at 1 cubic foot per revolution. A calibrated orifice, which is used to measure instantaneous flow rates, completes the train. The three thermometers used in this train are of the dial type, with a range of 25° to 125°F. A fourth thermometer in the heated portion of the box has a range up to 500°F. The manometer is an inclined type graduated in hundredths of inches of water. A similar manometer, depending on the expected range, is used to read the velocity head sensed by the pitot tube.

7.4.2. Assembling and Testing the Train

Before assembling the various sampling components, the following procedures should be performed in the laboratory. These procedures should be completed before each test series.

It is especially important that all components in contact with the sampling stream be carefully cleaned. Proper cleaning and lubrication, as described in Appendix B, will also ensure a leak-tight assembly.

Any other suspected malfunctions in the sampling train are also best diagnosed and repaired in the laboratory or shop. Frequent sources of mechanical problems include defective pumps (usually broken or stuck vanes), dry gas meter (erratic dial readings), timer or clock malfunctions, loose or broken electrical wires, damaged nozzle or pitot tube openings, and cracked glass parts.

7.4.2.1. Calibration of Train Components

In addition to the pitot tube calibration described in Section 7.1.2, the following calibrations should be made periodically.

Meter and orifice–The dry gas meter should be checked against a primary standard such as a large wet test meter, an accurate orifice, or a Bell Prover. With the meter accuracy determined, the orifice mounted on the meter outlet can be calibrated as described in Appendix C.

Sample box thermostat–The thermostat in the heated sample box compartment is calibrated by comparing its set temperature with a mercury thermometer. To accomplish this, the heater and blower should be turned on, and the thermostat set at 250°F. When the temperature has stabilized, the reading should be noted and the thermostat adjusted, if required, to yield a value of 250°F. The thermostat scale should also be adjusted to indicate 250°F.

Thermometers–The stack-gas thermometer and all thermometers used in the sampling train should be calibrated periodically at a point near their expected operating range. For lower temperature ranges, this may be accomplished by placing the stem into hot water and comparing the readings to a mercury bulb thermometer in the same water. For higher temperatures, an oven or hot gas stream may be used for calibration checks.

7.4.2.2. Assembling Train Components

The basic assembly of the sampling train for field use is facilitated by the use of two basic units or modules and connecting hardware.

The first module is the sample box. It consists of the probe; the cyclone (if used) and filter, both of which are placed in the heated portion of the box; and the four impingers in the cooled portion of the box. Before assembling the rest of the train, a numbered and tared glass fiber filter is placed into the filter holder (rough face should face upstream), and the filter number is recorded on the meter data sheet. The cyclone and filter holder are clamped together at the ground-glass ball and socket connectors with positive-lock pinch clamps. A light coating of silicone grease is applied to the outer portion of the male

* Usually 100 ml is used. Other liquids may also be used, depending on the particular gas to be absorbed.

ground-glass joints. The inlet to the cyclone is then temporarily sealed until the train has been completely assembled and checked (a glass ball held in place with a pinch clamp has been found useful for sealing the cyclone).

The four impingers are then placed in the cold section of the sampling train. The first two impingers are each filled with 100 ml of distilled, high-resistance, deionized water; the third impinger is dry; and the last impinger is filled with approximately 200 grams of weighed (± 1 g) dry silica gel (indicating type, 6 to 16 mesh). The impingers are connected with U-shaped connectors and positive-lock pinch clamps. The first impinger is connected to the filter outlet with a glass L-shaped adapter.

The second module, which consists of the meter box, contains the vacuum pump, dry gas meter, manometers, flow control valves, orifice flow meter, timer, and associated connecting tubing and wiring. This module is preassembled and requires no internal field connections.

The sample box and meter box are connected by an umbilical line consisting of the main vacuum line, the two pitot-tube connection lines, four electrical wires (two for the probe heater, and two for the sample box), and a ground wire. The vacuum line is attached to a check valve-thermometer assembly on the last impinger and connected to the meter box pump inlet with quick disconnects.

With the meter box and sample box connected, the heaters can be started and ice and water placed into the ice-water portion of the sample box. The train can then be checked as described in Section 7.4.2.3. A probe of the desired length is then selected, the appropriate nozzle is attached to the front of the probe, and the probe is marked with crayon or tape to indicate the described sampling point locations. If not permanently mounted, the pitot tube and stack-gas thermometer are now also attached to the probe.

7.4.2.3. Testing the Sampling Train

To test the sampling train for proper functioning prior to a field test, the train should be completely assembled, the heaters turned on, and the manometers set at zero. The vacuum pump is then turned on (with the vacuum line not connected), and a quick check is made of the orifice calibration at 0.75 cubic foot per minute to determine any malfunction in the meter or orifice connections. All thermometers should be checked at this time to ensure that they are reading approximately the correct values. The train is then checked for leaks by plugging the cyclone inlet, adjusting the vacuum to 10 and 15 inches of mercury, respectively, closing the pump bypass valve, and checking for flow through the dry gas meter. If a leakage rate greater than 0.02 cubic foot per minute is obtained, the train should be checked for leaks and the procedure repeated until the leakage rate does not exceed 0.02 ft^3/min. The final leakage rate should be carefully noted because the leakage volume has to be subtracted from the actual sample volume during actual test work. After the leak test, release the vacuum by slowly unplugging the cyclone inlet before opening the bypass valve and shutting off the pump. Failure to follow this procedure may cause air to flow backwards through the train and rupture the filter. The probe assembly should now be connected to the cyclone.

7.5. SAMPLING PROCEDURE

7.5.1. Location of Sampling Points

Under most conditions, the location of sampling points will be the same as those used for the velocity traverse, as determined in Section 7.1.1. Points with no positive velocity readings, however, should not be sampled. When such points are encountered, read the velocity and proceed to the next point. Only points that lie at the centroid of the subareas should be sampled.

7.5.2. Length of Sampling Periods

Each traverse point should be sampled for an equal time increment. A 5-minute sampling period per point is desirable; however, a 2-minute period is an acceptable minimum. A 1-hour total sampling period is usually the minimum total sampling time for one test. This time may vary considerably, however, depending on the process. At least two tests should be made. Any test that, upon completion, is found to have contained an error in sampling or analysis, or that is not within ± 10 percent of the calculated isokinetic rate should be repeated. During cyclic operation, at least one complete cycle should be sampled to obtain an average particulate emission value.

7.5.3. Operation of Sampling Train

After all the equipment has been checked and found to be functioning properly, the top of the Particulate Field Sampling Meter Data Sheet (Figure 7-10) should be filled in. Next, the initial dry gas meter reading should be carefully taken.

Plant _____ Filter No. _____

Run Number _____ Barometric Pressure, in. Hg _____

Location _____ Assumed Moisture, % _____

Date _____ Time _____ Assumed Meter Temp., °F _____

Operator _____ Stack Gauge Pressure, in. H_2O ___ _____

Sample Box Number _____ Probe Tip Diameter, in. _____

Meter Box Number _____

$\Delta H_@$ _____ 'C' Correction Factor _____ ___

Point	Time, min.	Dry Gas Meter			Velocity head Δp, in. H_2O	Orifice ΔH, in. H_2O	Pump vacuum, in. Hg	Box temp., °F	Impinger temp., °F	Stack temp., °F
		Volume, ft^3	Inlet temp., °F	Outlet temp., °F						

COMMENTS: Leakage Rate @ ___ inches Hg = _____

Figure 7-10. Particulate field sampling meter data.

The cover should then be removed from the nozzle tip, and the probe, along with the temperature-indicating device and pitot tube, should be placed in the duct until the nozzle reaches the first sampling point. The pitot reading and the desired ΔH found on the nomograph should be recorded along with the stack temperature. Stack pressure can be ignored if it was found to be insignificant during the preliminary traverse.

To begin testing, the on-off valve should be placed in the off position, the bypass valve should be completely opened, and the timer should be set at zero.* Record the clock time and turn the vacuum pump on. The actual ΔH should be adjusted to match the desired ΔH by first turning the on-off valve to on and adjusting the pump bypass valve.

7.5.4. Recording Data during Test Period

During the test period, pertinent data relating to the operation of the sampling train must be recorded in order to ensure both the proper operation of the train and the validity of the sample, and to provide necessary data for subsequent computations.

Figure 7-10 is a sample field data form that may be used while the particulate sample is being obtained. All data should be carefully entered immediately by the operator. In addition, any unusual observations in meter readings or process conditions should be noted; these notations might explain any results that appear to be anomalous. These readings should be taken at the beginning of sampling at each point or, if sampling at only one point, at 5-minute intervals.

The initial and final dry gas meter readings are most important. The pitot readings and the stack temperature readings are also important because they will be used to compute stack-gas flow after completion of the test.

When testing has been completed, the vacuum pump should be turned off and the final set of readings taken. Turn off the heater, blower, and probe heat switches, and remove the probe from the sampling port. The nozzle tip should be covered as soon as possible to avoid contamination or loss of sample. Loosen the probe clamp on the front of the sample box, and disconnect the probe from the cyclone inlet. Both the end of the probe and the inlet to the cyclone should be covered. After the umbilical cord has been disconnected from the sample box, the last impinger should be covered, and the probe and sample box should be moved to the sample cleanup area.

Various process parameters must also be recorded during the test period. The exact type of process data to be obtained will, of course, vary with the process. As a general guideline, all factors that have a bearing on the emissions should be recorded at approximately 15-minute intervals. These factors will include process or fuel weight rate, production rate, temperature and pressure in the reactor and/or boiler, control equipment, fan and/or damper settings, pressure drop or other indicator of particulate collection efficiency, and opacity of exit plume. Figure 7-11 through 7-13 provide sample forms for combustion, incineration, and process sources, respectively. Pertinent data obtained in the preliminary plant survey (Section 6.1) should also be checked at this time.

7.5.5. Sampling Problems

Some problems encountered during actual sampling are equipment malfunctions and inability to maintain isokinetic flow because of a high-pressure drop through the train. Malfunctions can best be prevented through a comprehensive, routine maintenance program and a careful check of the equipment before starting to sample.

Increased pressure drop through the sampling train is usually caused by a buildup of particulates on the filter. To try to prevent this, the temperature in the filter box should be maintained above 225°F. Spare filters, mounted in their holders, should also be prepared prior to testing in order to facilitate replacement with a new filter. If the filter is kept in a preheated box, sampling can be restarted almost immediately. The number of the new filter and the time of test interruption must be recorded immediately on the field data sheet.

7.6. DISASSEMBLY AND PARTICULATE CLEAN-OUT PROCEDURE

Upon completion of the sampling run, the sample box should be disconnected from the meter box and allowed to cool. The probe may be disconnected for ease in handling, and its open ends should be carefully sealed. The inlet and outlet of the sampling train should also be sealed before the train is transported to a clean area for disassembly. The various sampling train components are then disconnected, one at a time, and the collected sample is

* When the stack gas is under more than about 1 inch of mercury gauge pressure, the on-off valve should be left in the on or open position to avoid pressure buildup in the train. Sampling must then start as soon as the probe is inserted.

Test No. _____ Date _____

Name of Company _____

Location and Description of Boiler _____

_____

Type of Boiler _____ Capacity _____ 1000 lb steam/hr

Type of Fuel _____

Date Recorder _____

Time

_____

Fuel Rate

Steam Rate,
1000 lb/hr

Combustion
Air Rate,
1000 lb/hr

Steam Pressure

Steam
Temperature

I.D. Fan, rpm

I.D. Fan, amps

Pressures, in. H_2O

Furnace Outlet
Collector Inlet
I.D. Fan Inlet

Plume Opacity

Fuel Composition (As Weighed),
Btu/lb
% Moisture

% Ash

% S

% Volatile Matter

% Fixed Carbon

Ultimate Fuel Analysis

Figure 7-11. Boiler operating data.

Test No. _____ Date _____

Name of Company _____

Location and Designation of Unit _____

_____

Type of Incinerator _____

Type of Control Equipment _____

Type of Grate _____

Grate Speed _____

Type of Refuse Burned _____

Approximate Moisture Content _____

Data Recorder _____

Time	Material Charged, lb	Primary Chamber Draft		Secondary Chamber		Plume	I.D. Fan	
		Overfire, in. H_2O	Underfire, in. H_2O	Draft, in. H_2O	Temp., °F	Opacity, %	rpm	Amp
Tot.	Tot.	Avg.	Avg.	Avg.	Avg.	Avg.		

% of time afterburners are in operation _____

Fuel rate to afterburner _____

Figure 7-12. Incinerator operating data.

Test No. _____ Date _____

Name of Company _____

Location and Description of Process _____

_____

Capacity and Characteristics of Process and/or Product _____

_____

_____

_____

Raw Materials _____

Fuel Used _____

Time

Raw Material Feed Rate

Fuel Rate
Reactor Temp.
Reactor Pressure
Product Rate
Sidestream Rates

Recycle Stream
Rates

Exit Plume
Opacity

Figure 7-13. Process operating data.

removed and placed in a numbered container. A record of the containers and the samples should be made, and the record should accompany the samples to the lab (Figure 7-14).

First Container: Filter Holder–Remove the glass fiber filter paper from the holder and place it in a glass or inert plastic container. Use forceps in handling the filter. Any segments of the filter that adhere to the holder should be scraped off and included with the filter. Seal the container with masking tape and mark it appropriately.

Second Container: Probe, Cyclone, Cyclone Flask, Front Half of Filter Holder, and Connecting Tubing–The insides of these components should be wiped with a rubber policeman, and any loose particulate should be placed in the containers holding the probe contents. To remove all particulate and organic matter adhering to the inside walls, these parts should be rinsed with acetone and washed into the same container.

Third Container: Impinger Liquids–Carefully pour the water from the first three impingers into a graduated flask and record the volume to within ±1 milliliters. When determination of condensables is desired, this water should be quantitatively poured into a container. The first three impingers and all connecting tubing should then be rinsed with distilled-deionized water into the same container. If any visible particulates appear on the fritted glass filter support or the back half of the filter holder, these should also be added to this container. The container is then sealed with masking tape and labeled. If the impinger contents are not to be measured, the impinger solution may be discarded after its volume has been measured.

Fourth Container: Silica Gel–The silica gel from the fourth impinger should be quantitatively transferred to a glass or inert plastic container, designated as No. 4 and sealed. Use only dry brushing to remove the silica gel; do not wash.

Fifth Container: Organic Matter–To ensure removal of any condensed organic matter that tends to adhere to the inside walls of the glassware, the fritted glass filter support, the back of the filter holder, the first three impingers, and all connectors should be rinsed with acetone into a container. This container should be also sealed and labeled. This step may be omitted if the impinger fraction of the sample is not desired.

---

* Desiccate at 70°F ± 10°F under an atmosphere with a moisture content of less than 0.75 percent by volume.

7.7. PARTICULATE ANALYSIS

After the particulate fractions have been placed in their respective sealed containers, the containers should be carefully packed in a locked box, and promptly transferred to the laboratory. In the laboratory, the following analytical procedures should be performed on each of the sample containers.

First Container–The filter and any loose particulates or pieces of filter in this container should be quantitatively transferred to a tared weighing dish. This material should then be dried in a desiccator until a constant weight is obtained.* For highly organic particulate matter, a drying period of 2 to 3 days is appropriate. After drying, weigh the sample and weighing container on an analytical balance to the nearest 0.5 milligram. Record the weights on a standard laboratory form such as the one shown in Figure 7-14.

Second Container–The acetone washings from the container should be quantitatively rinsed with acetone into a clean, small tared beaker and evaporated to dryness at 70°F ± 10°F and at atmospheric pressure. The beaker and residue should then be placed in a desiccator for 24 hours, after which they must be weighed to the nearest 0.5 milligram. Record the data on the form illustrated in Figure 7-14.

Third Container–The water solution from the impingers should be placed in a separatory funnel and extracted with three 25-cc portions of chloroform followed by three 25-cc portions of ethyl ether. The ether and chloroform extracts should be combined and transferred to a clean tared beaker and evaporated to dryness at 70°F ± 10°F and 1 atmosphere pressure under a hood. The sample should then be dried in a desiccator for 24 hours and weighed to the nearest 0.5 milligram. The water remaining after extraction must be placed in a tared beaker and evaporated at 212°F. The residue should be dried and weighed.

Fourth Container–The silica gel and its container must be weighed to the nearest gram.

Fifth Container–The acetone washings in this container should be quantitatively rinsed into a clean tared beaker and evaporated to dryness at 70°F ± 10°F and 1 atmosphere pressure under a hood. The beaker and residue should then be desiccated for 24 hours and weighed to the nearest 0.5 milligram.

WEIGHT OF PARTICULATE COLLECTED

FIELD CONTAINER NUMBER	TOTAL FINAL WEIGHT, mg	TARE WEIGHT, mg	WEIGHT GAIN, mg
FILTER NO.		_____ FILTER _____ CONTAINER	
PROBE AND NO. CYCLONE			
IMPINGER NO. ORGANICS			
WATER NO. SOLUBLES			
ACETONE NO. WASHINGS			
TOTAL WEIGHT OF PARTICULATES COLLECTED, W_p =			x 2.2×10^{-6} = lb x 15.4×10^{-3} = gr

Plant _____

Run No. _____

Location _____

Received from ___ Received by _____

Analyzer _____

Date Analyzed _____

VOLUME OF MOISTURE COLLECTED

	FINAL VOLUME, ml	INITIAL VOLUME OR WEIGHT	VOLUMETRIC GAIN, ml
Impingers		-200 ml	
Silica Gel Container No.		- g	
TOTAL VOLUME OF WATER COLLECTED, V_T =			ml x 0.047 = scf

Figure 7-14. Particulate analysis data (to accompany samples from field to laboratory).

7.8. THE TEST REPORT

The emission test report should contain all of the pertinent data leading up to the test, a description of the process and the operating conditions under which tests were made, the results of the tests, and test procedures. The test report should enable a technically trained person to understand what was done and what the results were. Because the test reports may at times be used as legal evidence, they must be carefully prepared. Summaries of field test data should be included in order to allow a knowledgeable engineer to check the results and obtain an idea of their accuracy.

7.8.1. Format of Test Report

The exact format of the test report, and the extent to which each section of the report is developed, will vary widely from agency to agency and depend mainly on the intended use of the finished report. A suggested format of the test report is presented below:

Test Objective–This introductory section presents the reasons for performing the test series, the location of the plant, the processes that were tested, the location of test sites, the emissions measured, the test team and owner's personnel, the dates of the test work, and any other special comments or background information that are pertinent to the test purpose and the results.

Summary of Results–A summary will serve to provide the reader with a short synopsis of the tests and a tabular summary of pertinent operating and emission data.

Process Description–A description of the process and a schematic diagram of the flow of materials through the process are desirable to provide the reader with an understanding of the process. The test locations should be clearly indicated on this schematic diagram. Tables of process weight rates, temperature, gas flows, production rate, etc. that occurred during the test period should be included in this section. Capacity of the process equipment should also be included.

Test Results and Discussion–A detailed summary of all test results must be presented for each test run. A discussion of these results pertaining to their reliability and their relation to the process may also be presented. Variations in emissions should be explained.

Sampling and Analytical Procedures–The sampling techniques and analytical procedures used to obtain all emission results should be listed and referenced to a standard method. Modifications to the sampling techniques should be carefully explained when used.

Appendices–The appendices, which should contain summaries of the detailed field test data, may also contain a summary of applicable regulations.

7.8.2. Presenting the Results

Emission data should be presented in readily understood tabular form. The results should be related to the particular process or test condition in the summary tabulations. The units used to express the results will vary with the objectives of the stack test. In most cases, emission on a basis of pounds per hour or pounds per ton of process weight should be presented, in addition to a concentration value. In all cases, units identical to those used in the local regulation should be used. Specify the temperature and pressure used to convert gas volumes from stack conditions to standard conditions.* Clearly indicate if a concentration value has been converted to the dry basis and/or to a certain excess air and/or percent CO_2 value.

Figure 7-15 presents a suggested data summary for particulate emissions from fuel combustion processes. Similar tabulations should be used in presenting emission data from other processes. One method of summarizing test results, which may be used in the Appendix to the report, is shown in Figure 7-16.

7.8.3. Example Calculations

Reporting of emission results in a usable form always requires some calculations. These calculations are best illustrated by the following example, which uses equations previously presented in this section.

7.8.3.1. Determination of Stack-Gas Volume

Assume the following parameters were measured as explained in Section 7.1.

Stack dimension, 60 in. by 72 in.
Stack area, $A_s = 30$ ft^2
Barometric pressure, $P_b = 30.0$ in. Hg
Stack gauge pressure, $P_g = 1.4$ in. H_2O;
$P_s = 30.0 - 1.4/13.6 = 29.9$ in. Hg
Stack temperature, $T_s = 600°F = 1060°R$
Average square root of velocity head, $\Delta p = 0.55$ in. Hg

* 70°F (equivalent to 530°R) and 29.92 inches Hg are usually used as standard temperature and pressure.

Test No.	Steam rate, 100C lb/hr	Fuel rate	Flue gas				gr/scf	lb/1000 lb	lb/10^6 Btu
			Volume, scfm[a]	Temp., °F	% CO_2	% H_2O			

[a]Standard cubic feet per minute at 70°F and 29.92 inches Hg.

Figure 7-15. Format for presenting emissions from fuel combustion unit.

As determined from pitot-tube traverses (Figure 7-5) the molecular weight of stack gas (M. W.) is similar to that of air, which is 28.96. Assuming a Cp value of 0.85 for the type-S pitot tube used, the stack gas velocity (V_s) can be calculated

$$V_s = 174 C_p \sqrt{\Delta_{gT_s} \times \frac{29.92}{P_s} \times \frac{28.96}{M.W.}}$$

$$= 174 \times 0.85 \times 0.55 \sqrt{1060 \times \frac{29.92}{29.9}}$$

$$= 80.5\sqrt{1060}$$

$$= 2620 \text{ ft/min.}$$

Q_s = Volume = $A_s \times V_s = 30 \text{ ft}^2 \times 2620 \text{ ft/min.}$

$= 78{,}500 \text{ ft}^3\text{/min.}$

The volume at standard conditions of 70°F and 29.92 inches of mercury is:

$$Q_{ss} = Q_s \times \frac{530}{T_s} \times \frac{P_s}{29.92} = 78{,}500 \times \frac{530}{1060} \times \frac{29.9}{29.92}$$

$= 39{,}200$ scfm

This volume has the composition of the actual gas stream, but has been converted to standard conditions. Frequently it is desired to express volume on a dry basis; this may be done by factoring out the fraction of volume due to moisture. Thus, if the gas has a moisture content (W) of 10 percent (as determined in Section 7.1.4), the dry volume would be $Q_{ss}(100\text{-}W)/100$ or 39,200(100-10)/100 = 35,300 scfm (dry).

The gas volume may be converted to a weight basis by multiplying by its density at a given temperature and pressure. Densities are usually determined by comparing the molecular weight of the gas with that of air, i.e., density of gas = (M.W. of gas/28.96) x density of air.

In this example, the molecular weight of the gas is very similar to that of air and, therefore, its density is similar; namely 0.075 pound per cubic foot at 70°F and 29.92 inches of mercury.* The quantity of dry gas emitted on a weight basis is therefore:

$35{,}300 \text{ ft}^3\text{/min} \times 0.075 \text{ lb/ft}^3 = 2648 \text{ lb/min dry gas}$

7.8.3.2. Determination of Sample Gas Volume

The sample gas volume is equal to the gas that passed through the dry gas meter and the equivalent volume of water vapor trapped in the sampling train. If significant, the air in leakage should be subtracted from the meter volume. This quantity is then converted to standard temperature and pressure basis as shown in Figure 7-17.

The particulate concentration is equal to the particulate weight divided by the sample gas volume, and the total particulate emission is equal to the product of the concentration and total stack-gas flow. One must be very careful not to multiply concentrations or volume factors that are not at the same temperature, pressure, and moisture conditions. Any basis may be used, but it must be consistent throughout the calculation procedure.

7.8.3.3 Check on Isokinetic Flow Rate

A check on the rate of isokinetic flow actually maintained during the test period can be estimated on an average basis. This calculation does not ensure that isokinetic flow was maintained constant at every instant, but it does give the average percent of isokinetic flow maintained at each sampling point. This equation, which appears on the bottom of Figure 7-17, can be used to determine the ratio of the average stack-gas velocity to the average velocity in the nozzle; the ratio should be between 90 and 110 at each point. Before computing individual points, a check on the test as a whole should be made to see if it falls within the specified limits.

7.8.3.4. Converting to Other Emission Standards

Frequently emission must be expressed on a basis other than pounds per hour or grains per scf. Other emission standards are especially popular in combustion processes in which emissions are related to fuel or heat input and to excess air rates.

Grains per scf at specified rate of excess air—Conversion to this basis requires measurement of the excess air rate. This can be determined by measuring the CO_2, O_2, and CO content of the exit gases. Excess air is then computed from the equation:

$$\% X_s = \frac{\% O_2 - 0.5\% CO}{0.264\% N_2 - (\% O_2 - 0.5\% CO)}$$

Where $\% N_2 = 100\text{-}(\% CO_2 + \% O_2 + \% CO)$

Correction to 50 percent excess air, for example, at standard conditions is obtained by multiplying the grain loading computed at STP by the ratio: (100 + measured X_s)/150.

For 80 percent excess air $C_{50\%} = C \times 180/150$.

* Density of air at other conditions is obtained by the equation:

$$0.075 \times \frac{530°R}{\text{Temperature}} \times \frac{\text{Pressure}}{29.92 \text{ in. Hg}}$$

Test No. _____
Date _____
Name _____
Address _____
_____

Process Tested _____

1. Sampling Station _____
2. Material Collected _____
3. Operating Condition _____
4. Avg. Flue Gas Velocity, ft/min. _____
5. Avg. Flue Gas Temp., °F _____
6. Area of Duct, ft^2 _____
7. Gas Flow Rate, scfm _____
8. Sampling Nozzle Diam., in. _____
9. Avg. Meter Sampling Rate, ft^3/min. _____
10. Testing Time, min. _____
11. Avg. Meter Temp., °F _____
12. Sample Gas Vol.-Meter Cond., ft^3 _____
13. Sample Gas Vol.-Standard Cond., scf _____
14. Water Vapor Condensate, ml Volume, scf _____
15. Total Sample Gas Volume, scf _____
16. Weight Collected, grams _____
17. Total Weight, g _____
18. Concentration, gr/scf _____
19. Concentration, gr/scf @ 12% CO_2 _____
20. Concentration, % by volume _____
21. Concentration, ppm by volume _____
22. Emission Rate, lb/hr _____

COLLECTOR EFFICIENCY

23. Material to Collector, lb/hr _____
24. Loss to Atmosphere, lb/hr _____
25. Efficiency, % _____

Test Conducted By _____
Analysis By _____
Calculations By _____

Figure 7-16. Summary of emission test data.[4]

Plant No. _____ Calculated by _____

Run No. _____ Checked by _____

Location _____ Date _____

Meter Volume _____ (Figure 7-10)

Leakage Volume _____ (Leakage rate x sampling time)

Net Sample Volume, Q_m _____ ft^3

Average Meter Temperature, T_m _____ °F + 460 = _____ °R.

$P_m = P_b$ = _____ in. Hg

Standard Sample Volume,

$Q_{ms} = 17.7 \times Q_m \times \frac{P_b}{T_m} = 17.7 \times$ _____ x _____ = _____

Equivalent Moisture Volume, Q_v = _____ scf (Figure 7-14)

Total Sample Volume, $Q_t = Q_{ms} + Q_v$ = _____ = _____ scf

Particulate Sample Weight, W_p = _____ gr (Figure 7-14)

Particulate Concentration, $C = \frac{\text{_____}}{Q_t}$ = _____ gr/scf

Particulate Concentration,

dry basis $C_d = C \times \frac{100}{100 - W}$ = _____ gr/dry scf

Emission Rate,

lb/hr, $E = C \times Q_{ss} \times 0.00857$ = _____ x 0.00857 = lb/hr

$$\% \text{ Isokinetic, } I = \frac{V_s}{\frac{Q_t}{t \times A_n} \times \frac{T_s}{530} \times \frac{29.92}{P_b}} \times 100$$

t = sample time

A_n = area of sample nozzle, ft^2

V_s = stack-gas velocity (Figure 7-5)

Figure 7-17. Particulate sampling calculations.

Grains per scf at specified oxygen content–Converting a grain loading to a specified O_2 content is accomplished by:

$$C \times \frac{20.9\text{-specified \% } O_2}{20.9\text{-measured \% } O_2}$$

Thus, if the basis is 6 percent O_2, and 10 percent O_2 was actually measured, then the corrected grain loading is $C_{6\% O_2} = C \times 14.9/10.9$.

Grains per scf at specified carbon dioxide content–Converting a grain loading to a certain CO_2 content is accomplished by:

$$C \times \frac{\text{specified \% } CO_2}{\text{measured \% } CO_2}$$

If the specified CO_2 content is 12 percent, and the measured CO_2 content in the exit gas stream is 4 percent, then the corrected concentration would be:

$C_{12\% CO_2} = C \times 12/4$.

Pounds of emission per 1000 pounds of dry flue-gas–For gas streams similar to air in composition, i.e., with a molecular weight between 28 and 30, concentration can be approximately converted to this basis at standard conditions as follows: $C_d \times 1.90$ at standard conditions of 70°F and 29.92 inches of mercury. If correction to an excess air value, or percent CO_2, is also required, these corrections are applied in the same manner as previously explained. For other gas compositions or nonstandard temperature or pressure conditions, the gas volume should be converted to a weight basis by multiplying by the appropriate density. The emission on a pound-per-hour basis is then divided by this value.

Pounds per 10^6 Btu–This emission expression, commonly used for combustion processes, is obtained by dividing the emission in pounds per hour by the heat input, expressed in millions of Btu entering a unit in the same hour. For bituminous-coal-fired units, emission expressed on this basis can be approximated by:

$$C_{12\% CO_2} \times 1.9$$

8. SIGNIFICANCE OF ERRORS IN SOURCE SAMPLING[13]

The procedure for determining pollutant emission rates by stack sampling involves the measurement of a number of parameters. Errors of measurement associated with each parameter combine to produce an error in the calculated emission rate. Measurement errors are of two types: bias and random. Bias errors, which usually occur as a result of poor technique, cause the measured value to differ from the true value in one direction. Typically, this operator error can be minimized by proper calibration and adequate training in instrument operation. Random errors, which result from a variety of factors, cause the measured value to be either higher or lower than the true value. Such errors are caused by the inability to read scales very precisely, as well as by poor quality and lack of sensitivity of the measurement device. The usual assumption is that random errors are normally distributed with a known (or unknown) mean and standard deviation.

The emission rate of particulates from a stack can be expressed as follows:

$$E = K_1 C Q_{ss} \tag{8-1}$$

where:

E = emission rate, lb/hr
C = particulate concentration, gr/scf
Q_{ss} = volume of gas in stack, scfm
K_1 = constant to yield proper units

but,

$$C = \frac{W_p}{Q_t} \tag{8-2}$$

where:

W_p = weight of particulate sample, gr
Q_t = total sample volume, scf

and

$$Q_{ss} = \frac{K_2 A_s C_p P_s}{T_s} \left(\frac{\Delta p T_s}{P_s M_s} \right)^{1/2} \tag{8-3}$$

where:

K_2 = constant to yield consistent units
A_s = area of stack, ft^2
C_p = pitot tube coefficient
Δp = velocity head of stack gas, inches H_2O
T_s = absolute temperature of stack gas, °R
P_s = absolute pressure of stack gas, inches Hg
M_s = molecular weight of stack gas

Substituting Equations 8-2 and 8-3 into 8-1 yields:

$$E = \frac{K W_p A_s C_p P_s}{Q_t T_s} \left(\frac{\Delta p T_s}{P_s M_s} \right)^{1/2} \tag{8-4}$$

This is equivalent to:

$$E = \frac{K W_p A_s C_p}{Q_t} \left(\frac{\Delta p P_s}{T_s M_s} \right)^{1/2} \tag{8-5}$$

The maximum relative error can be determined by use of the logarithmic differential of these equations.[13]

$$\frac{dE}{E} = \frac{dW_p}{W_p} + \frac{dA_s}{A_s} + \frac{dC_p}{C_p} + \frac{dQ_t}{Q_t} + \frac{1}{2}\left(\frac{d\Delta p}{\Delta p} + \frac{dP_s}{P_s} - \frac{dT_s}{T_s} - \frac{dM_s}{M_s} \right) \tag{8-6}$$

The weight of particulates (W_p) can be determined by the use of an analytical balance with sensitivity approximately ± 0.1 milligram. For an industrial process, the total sample weight is typically about 100 milligrams, whereas for some combustion processes, the typical sample may be approximately 200 milligrams.* Thus the relative error is:

$$\frac{dW_p}{W_p} = \pm \frac{0.1 \text{ mg}}{100 \text{ mg}} = 0.001 \text{ or } 0.1\% \text{ (industrial process)}$$

* These values could, of course, vary widely and are used only as examples.

$$\frac{dW_p}{W_p} = \pm \frac{0.1 \text{ mg}}{200 \text{ mg}} = 0.0005 \text{ or } 0.05\% \text{ (power plant)}$$

The area of the stack (A_s) is determined by actual measurements of length and width for a rectangular cross section and of the diameter for a circular cross section. The area of each type of duct is:

$$A_s = LW$$

or

$$A_s = \frac{\pi}{4}(D)^2$$

then

$$\frac{dA_s}{A_s} = \frac{dL}{L} + \frac{dW}{W}$$

(rectangular)

and

$$\frac{dA_s}{A_s} = \frac{2dD}{D}$$

(circular)

A typical procedure for determining the inside measurement of a stack is to insert a rod into the stack, mark the rod, and measure with a steel rule. Such a procedure should yield a measurement correct to about 0.25 inch. Thus, for a circular stack with a diameter of 36 inches, the relative error is:

$$\frac{dA_s}{A_s} = \frac{2dD}{D} = \frac{2(0.25)}{36} = 0.013 \text{ or } 1.3\%$$

Naturally the relative error would decrease with stacks having larger inside dimensions.

The coefficient of a type-S pitot tube (C_p) varies from 0.83 to 0.87. If the average is assumed to be 0.85, the maximum error is ± 0.02. The relative error is:

$$\frac{dC_p}{C_p} = \pm \frac{0.02}{0.85} = \pm 0.024 \text{ or } 2.4\%$$

The total sample volume (Q_t) is determined by:

$$Q_t = \frac{17.7\, Q_m P_b}{T_m} + Q_v \qquad (8\text{-}7)$$

where:

Q_m = net sample metered volume, ft^3
T_m = average absolute meter temperature, °R
P_b = barometric pressure, in. Hg
Q_v = equivalent moisture volume, scf

$$\frac{dQ_t}{Q_t} = \left(\frac{17.7\, P_b dQ_m}{T_m} - \frac{17.7\, Q_m P_b dT_m}{T^2_m} + \frac{17.7\, Q_m dP_b}{T_m} + dQ_v \right) / Q_t \qquad (8\text{-}8)$$

The volume of gas metered (Q_m) is typically between 40 and 50 cubic feet, and the meter should be read to the nearest 0.01 cubic foot (d Q_m). Likewise the barometric pressure (P_b) is generally near 29.9 inches of mercury and should be read to the nearest 0.01 inch mercury (d P_b). The equivalent moisture volume (Q_v) can be determined by:

$$Q_v = 0.0474\, Q_1$$

where:

Q_1 = moisture collected, ml

then

$$dQ_v = 0.0474\, d\, Q_1$$

The amount of moisture collected is quite often near 100 milliliters and the precision of measurement is about ± 2 milliliters. Thus,

$$dQ_v = 0.0474\, dQ_1$$

$$= 0.0946 \text{ or } 9.46\%$$

The absolute temperature of the meter (T_m) is determined by:

$$T_m = T + 460$$

where:

T = meter temperature

$$\frac{dT_m}{T_m} = \frac{dT}{T_m}$$

This measurement of temperature is usually made with a bimetallic thermometer with a precision of ± 2°F. The range of temperature readings is from 80° to 120°F. Assume an average temperature of about 100°F or 560°R:

$$\frac{dT_m}{T_m} = \frac{2}{560} = 0.0036 \text{ or } 0.36\%$$

Substituting these quantities in Equation 8-8 and using the algebraic signs of each error term to produce the maximum error yields:

$$\frac{dQ_t}{Q_t} = 0.0006 \text{ or } 0.06\%$$

Differential pressure (Δp) is usually measured with an inclined manometer. The sensitivity is generally assumed to be about ± 0.01. For Δp readings of approximately 0.05, the maximum error is:

$$\frac{d\,\Delta p}{\Delta p} = \frac{0.01}{0.05} = 0.20 \text{ or } 20\%$$

The absolute pressure of the stack gas (P_s), as determined by Equation 7-4, is:

$$P_s = \frac{\pm p_s}{13.6} + P_b$$

where:

p_s = stack gauge pressure, inches H_2O

$$\frac{dP_s}{P_s} = \frac{\frac{dp_s}{13.6} + dP_b}{P_s}$$

Stack-gas pressure (p_s) is measured with a manometer that can be read to the nearest 0.1 inch of water (dP). Typically the stack-gas pressure is around ± 2 inches of water, thus

$$\frac{dP_s}{P_s} = 0.0004 \text{ or } 0.04\%$$

Stack-gas temperature (T_s) measurements are usually made with mercury-glass thermometers, thermocouples, liquid-filled bulb-thermometers, or bimetallic thermometers. Typical properly calibrated thermometers are accurate to within ± 5°F from 32° to 500°F, ± 10°F from 500° to 1000°F, and ± 20°F from 1000° to 2000°F. The maximum relative error would occur at about 1000°F.

$$\frac{dT_s}{T_s} = \pm \frac{20}{1000 + 460} = 0.014 \text{ or } 1.4\%$$

The equation for dry molecular weight in terms of Orsat readings for a typical combustion process is:

$$M_d = \frac{1}{100}\left[M_{CO_2}(R_{CO_2} - R_O) + M_{O_2}(R_{O_2} - R_{CO_2}) + M_{CO}(R_{CO} - R_{O_2}) + M_{N_2}(100 - R_{CO})\right] \quad (8\text{-}9)$$

where:

M_{CO_2} = 44 – molecular weight CO_2
M_{O_2} = 32 – molecular weight O_2
M_{CO} = 28 – molecular weight CO
M_{N_2} = 28 – molecular weight N_2
R_O = initial reading of Orsat
R_{CO_2}, R_{O_2}, R_{CO} are Orsat readings for each gas

Substituting the molecular weights into Equation 8-9 and differentiating yields:

$$\frac{dM_d}{M_d} = \frac{-0.44\,dR_O + 0.12\,dR_{CO_2} + 0.04\,dR_{O_2}}{M_d} \quad (8\text{-}10)$$

The error in reading the gas burette is generally ± 0.2 percent by volume, and a typical dry molecular weight is about 29. Thus the maximum error is:

$$\frac{dM_d}{M_d} = 0.0042 \text{ or } \pm 0.42\%$$

The maximum relative error in the emission rate (Equation 8-6) can be found by a summation of all of the above errors.*

$$\frac{dE}{E} = (0.1) + (1.3) + (2.4) + (0.06) + 1/2\,[(20) + (0.04) + (1.4) + (0.42)] = 14.8\%$$

* The error associated with the dry molecular weight (M_d) is used as the error for the actual stack gas (M_s).

Again, it should be emphasized that 14.8 percent is the maximum relative error if all of the individual errors are additive and not random.

A more realistic way of expressing error is to consider the error in terms of standard deviations. In this case, the error is expressed as 3 deviation (3σ) units about the mean.[14] The probable error can be calculated from:

$$3\sigma = \left[\sum_{i=1}^{n} A_i^2 \, (3\sigma)_i^2\right]^{1/2} \qquad (8\text{-}11)$$

thus

$$3\sigma_E = \left\{(0.1)^2 + (1.3)^2 + (2.4)^2 + (0.06)^2 + 1/4\left[(20)^2 + (0.04)^2 + (1.4)^2 + (0.42)^2\right]\right\}^{1/2}$$
$$= 0.104 \text{ or } 10.4\%$$

On the basis of this error analysis, the determination of emission rates by isokinetic stack sampling can be expected to be within 10.4 percent of the true mean 99.6 percent of the time. It is apparent that most of the sources of error contribute only in a very small way to the total error in the calculated emission rate. The most significant error results from the measurement of differential pressure (Δp) with the pitot tube.

APPENDIX A.

NOMOGRAPHS FOR USE WITH SAMPLING TRAIN

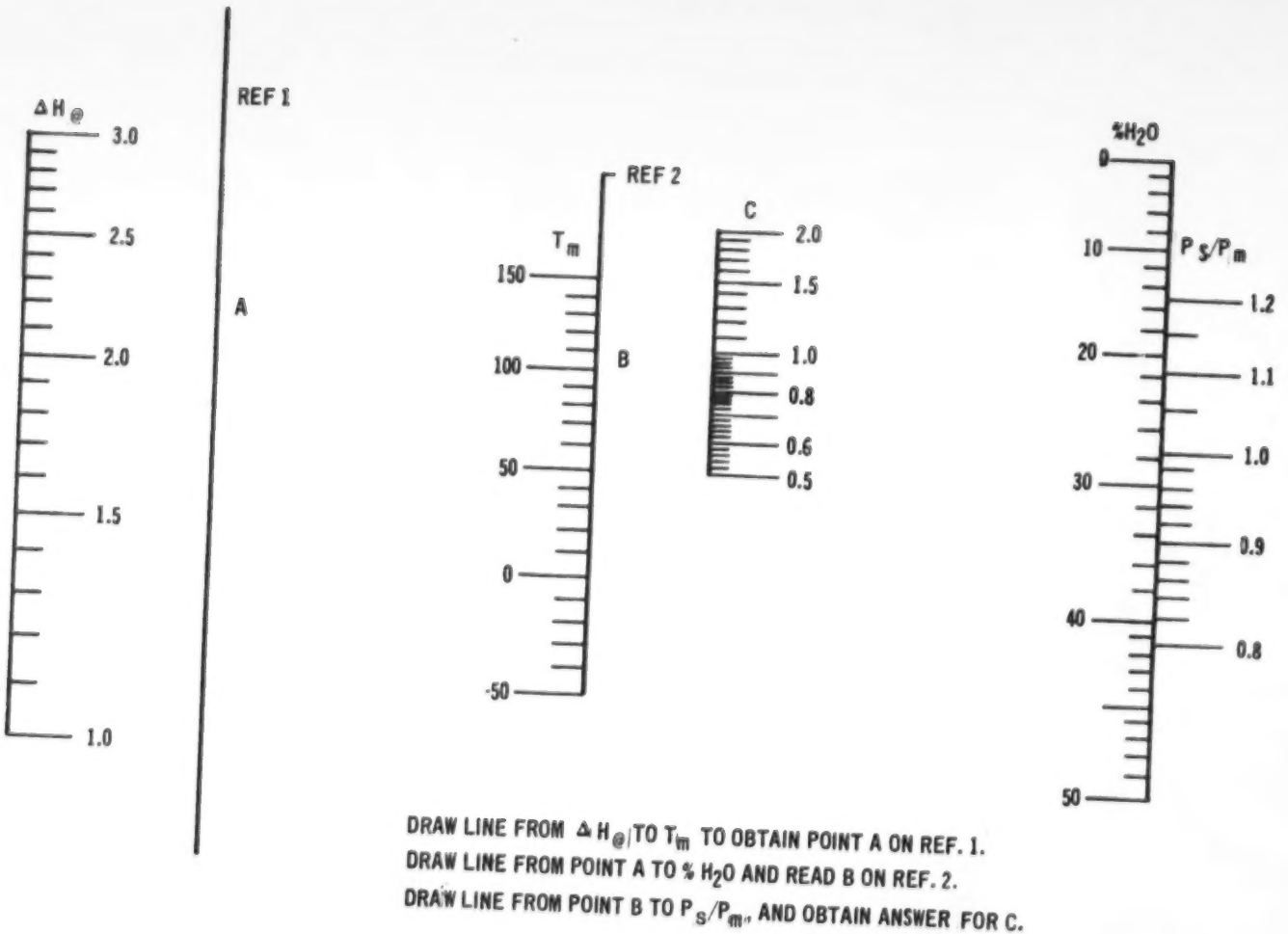


Figure A-1. Correction nomograph for use with Figure A-2.

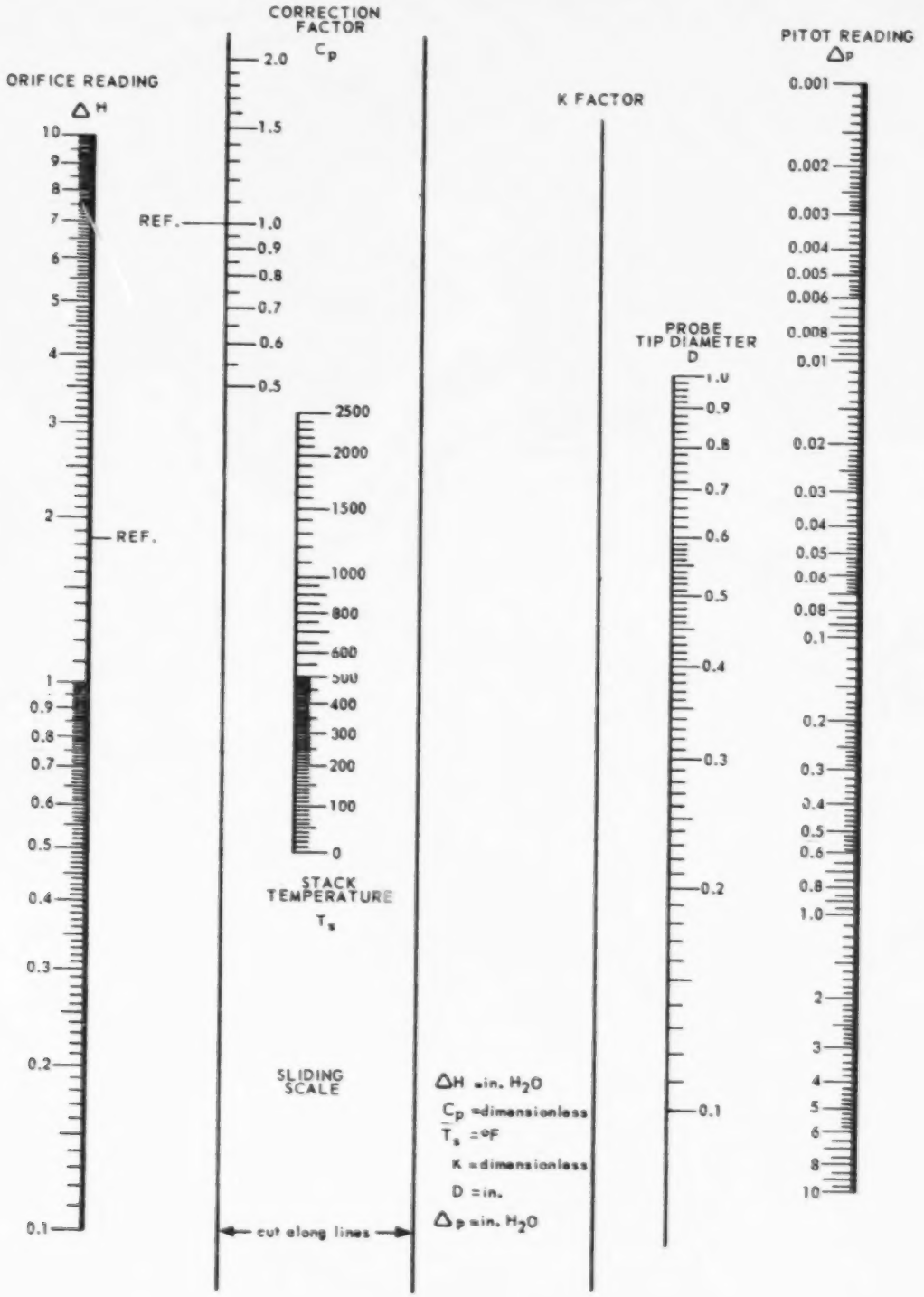


Figure A-2. Operating nomograph.

APPENDIX B.

CLEANING OF TRAIN COMPONENTS [15]

Small metal parts–Small stainless steel parts including quick connects, nozzles, check valves, unions, and socket joints should be cleaned by hand with water and a detergent, or with a sonic cleaning device and the recommended cleaner. After cleaning, the parts should be rinsed first with distilled deionized water and then with acetone to remove organics and promote drying. Quick connects and check valves should be lubricated very lightly with silicone grease, and the openings should be covered.

Probe sheath and pitot tube–The probe should first be stripped of the stainless steel union and quick connects. These parts can be cleaned together with the small metal parts. The rubber o-ring should be cleaned with water first and then acetone. The pitot tube and probe sheath should be scrubbed with acetone and water, and the pitot tube can be blown out with compressed air. After cleaning, the unions and quick connects should be reassembled. The glass probe should be inserted in the metal sheath, and the openings should be covered until ready for use.

Glass probe–Wipe the grease from the ground-glass ball joint, and then brush the probe and rinse it first with distilled, deionized water and then with acetone. A visual inspection should be made to determine if the probe is thoroughly clean inside. The dried glass probe should be placed in the cleaned stainless steel probe sheath, and the ends should be covered to avoid contamination.

Glass parts–All ground-glass joints must be wiped to remove any remaining grease. Then soak all pieces in a cleaning solution of dichromate and acid for 24 hours. The parts should next be washed in soap and water, rinsed with distilled deionized water, and then with acetone. A very thin coat of acetone insoluble silicone stopcock grease can then be applied to all of the inside (female) ground-glass joints. The impingers should then be reassembled. The glass, field-sample containers, and related glass cleanup equipment should be cleaned by this same procedure. All openings on the glass parts should be covered to avoid contamination.

Filter frit–The extra-course glass frit from the filter holder can be cleaned by placing it in boiling hydrochloric acid (under a hood) for 2 hours and then rinsing it first with distilled deionized water and then with acetone. If the frit does not appear clean, it should be boiled for 2 more hours in a solution of H_2SO_4 with a few drops of sodium or potassium nitrite added; rinse with distilled deionized water and acetone, and dry.

Miscellaneous–Manometers should be cleaned with either soap, naphtha, or gasoline. No other solution should be used to clean the manometer unless recommended by the manufacturer. The manometers should then be refilled with the appropriate liquids.

APPENDIX C.

ORIFICE CALIBRATION PROCEDURE [15]

The meter box containing the vacuum pump and dry gas meter should be connected to a large-capacity wet test meter (1 cubic foot per revolution) by connecting the meter box inlet to the outlet of the wet test meter. The orifice manometer should be carefully zeroed. The vacuum pump must then be turned on, the orifice ΔH set at 0.5 inch of water, and the system allowed to run for 15 minutes to equilibrate the temperatures. The following readings should be taken during the meter/orifice calibration: (1) cubic feet of air registered by the dry gas meter (CF_d), (2) temperature of the wet test meter in °F (T_w), (3) inlet temperature of the dry gas meter in °F (IT_d), (4) outlet temperature of the dry gas meter in °F (OT_d), (5) time in minutes (t) required for 5 cubic feet of air to flow through the train, and (6) barometric pressure in inches of mercury (P_b). The same procedure should be used with the manometer orifice setting at a ΔH of 1 inch of water, and the same data must be recorded. With the manometer orifice set at ΔH readings of 2, 4, 6, and 8 inches of water, respectively, 10 cubic feet of air should be allowed to flow through the wet test meter at each of these settings, and the same data should be recorded. From those data, Y and $\Delta H@$ can be determined for each calibration point. Y is the ratio of accuracy of the wet test to the dry gas meter. $\Delta H@$ (inches of H_2O) is the orifice differential that gives 0.75 cfm of air at standard conditions of 70°F and 29.92 inches of mercury. Figure C-1 illustrates a convenient form for recording these data and also gives the formulas used to calculate Y and $\Delta H@$.

If the calculated value for Y is not between 0.99 and 1.01, the dry gas meter will require adjustment according to the manufacturer's instructions. If the flow through the orifice at a setting of 1.84 ± 0.25 inch of H_2O is not 0.75 cfm, the orifice diameter should be increased or decreased as the case may be.

Once determined, $\Delta H@$ is constant for a given meter and orifice assembly and should be recorded on the meter box.

Date _____ Box No. _____ Meter No. _____ P_b _____

ΔH, in. H_2O	CF w	CF d	T w, °F	IT d, °F	OT d, °F	T d, °F	Time, t (min)
0.5	5						
1.0	5						
2.0	10						
4.0	10						
6.0	10						
8.0	10						

Calculation Y and $\Delta H_@$ at manometer orifice setting of 2.0

$$Y = \frac{CF_w P_b (T_d + 460)}{CF_d (P_b + \frac{\Delta H}{13.6}) (T_w + 460)} = _____$$

$$\Delta H_@ = \frac{0.0317 \ \Delta H}{P_b (OT_d + 460)} \left[\frac{(T_w + 460) \ t}{CF_w} \right]^2 = _____$$

Y = Ratio of accuracy of wet test meter to dry gas meter.

$\Delta H_@$ = Orifice pressure differential that gives 0.75 cfm of air at 70°F and 29.92 inches of mercury, in. H_2O.

P_b = Barometric pressure, in. Hg.

ΔH = Manometer orifice setting, in. H_2O.

CF_w = Cubic feet of air measured by the wet test meter, ft^3.

CF_d = Cubic feet of air measured by the dry gas meter, ft^3.

T_w = Temperature at the wet test meter, °F.

IT_d = Inlet temperature at the dry gas meter, °F.

OT_d = Outlet temperature at the dry gas meter, °F.

T_d = Average of the inlet (IT_d) and outlet (OT_d) temperatures at the dry gas meter, °F.

t = Time of test, minutes.

Tolerances

Y = 0.99 - 1.00 - 1.01

$\Delta H_@$ = 1.6 - 1.84 - 2.1

Figure C-1. Orifice calibration form.

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LIST OF SYMBOLS

A_n	Area of sampling nozzle, ft^2
A_s	Inside area of stack, ft^2
C	Particulate concentrations, gr/scf
C_p	Pitot tube correction factor
E	Emission rate, lb/hr
M_s	Stack-gas molecular weight
M_d	Stack-gas molecular weight (dry basis)
N	Number of sampling points
P_b	Barometric pressure, inches of Hg
p_s	Stack gauge pressure, inches of H_2O
P_s	Stack absolute pressure, inches of Hg
P_m	Average pressure at dry gas meter, inches of Hg (as used in this text $P_m = P_b$)
Q_s	Stack-gas volume, ft^3/min
Q_{ss}	Stack-gas volume, scfm
Q_m	Meter volume, ft^3 or rate, cfm
Q_v	Volume of condensed moisture, scf
Q_{ms}	Meter volume, scf
Q_t	Total sample volume, scf
T_m	Meter temperature, °F
T_s	Stack-gas temperature, °F
V_s	Stack-gas velocity, ft/min
W	Moisture content of stack gas, %
Δp	Velocity head, inches of H_2O
ΔH	Pressure drop across orifice, inches of H_2O
W_p	Particulate weight, gr or g

METRIC CONVERSION TABLE

Multiply	by	to obtain
acres	43 560	square feet
acres	4047	square meters
acres	1 562x10⁻³	square miles
acres	5645 38	square varas
acres	4840	square yards
amperes	1/10	abamperes
amperes	3x10⁹	statamperes
atmospheres	76 0	cms. of mercury
atmospheres	29 92	inches of mercury
atmospheres	33 90	feet of water
atmospheres	10 333	kgs. per sq. meter
atmospheres	14 70	pounds per sq. inch
atmospheres	1 058	tons per sq. foot
British thermal units	0 2520	kilogram-calories
British thermal units	777 5	foot-pounds
British thermal units	3 927x10⁻⁴	horse-power hours
British thermal units	1054	joules
British thermal units	107 5	kilogram-meters
British thermal units	2 928x10⁻⁴	kilowatt hours
B.t.u. per min.	12 96	foot pounds per sec.
B.t.u. per min.	0 02356	horse-power
B.t.u. per min.	0 01757	kilowatts
B.t.u. per min.	17 57	watts
B.t.u. per sq. ft. per min.	0 1220	watts per sq. inch
bushels	1 244	cubic feet
bushels	2150	cubic inches
bushels	0 03524	cubic meters
bushels	4	pecks
bushels	8 4	pints (dry)
bushels	32	quarts (dry)
centimeters	0 3937	inches
centimeters	0 01	meters
centimeters	393 7	mils
centimeters	10	millimeters
centimeter-grams	980 7	centimeter-dynes
centimeter-grams	10⁻⁵	meter-kilograms
centimeter-grams	7 233x10⁻⁵	pound-feet
centimeters of mercury	0 01316	atmospheres
centimeters of mercury	0 4461	feet of water
centimeters of mercury	136 0	kgs. per sq. meter
centimeters of mercury	27 85	pounds per sq. foot
centimeters of mercury	0 1934	pounds per sq. inch
centimeters per second	1 969	feet per minute
centimeters per second	0 03281	feet per second
centimeters per second	0 036	kilometers per hour
centimeters per second	0 6	meters per minute
centimeters per second	0 02237	miles per hour
centimeters per second	3 728x10⁻⁴	miles per minute
cubic centimeters	3 531x10⁻⁵	cubic feet
cubic centimeters	6 102x10⁻²	cubic inches
cubic centimeters	10⁻⁶	cubic meters
cubic centimeters	1 308x10⁻⁶	cubic yards
cubic centimeters	2 642x10⁻⁴	gallons

Multiply	by	to obtain
cubic centimeters	10⁻³	liters
cubic centimeters	2 113x10⁻³	pints (liq.)
cubic centimeters	1 057x10⁻³	quarts (liq.)
cubic feet	62 43	pounds of water
cubic feet	2 832x10⁴	cubic cms.
cubic feet	1728	cubic inches
cubic feet	0 02832	cubic meters
cubic feet	0 03704	cubic yards
cubic feet	7 481	gallons
cubic feet	28 32	liters
cubic feet	59 84	pints (liq.)
cubic feet	29 92	quarts (liq.)
cubic feet per minute	472 0	cubic cms. per sec.
cubic feet per minute	0 1247	gallons per sec.
cubic feet per minute	0 4720	liters per second
cubic feet per minute	62 4	lbs. of water per min.
cubic inches	16 39	cubic centimeters
cubic inches	5 787x10⁻⁴	cubic feet
cubic inches	1 639x10⁻⁵	cubic meters
cubic inches	2 143x10⁻⁵	cubic yards
cubic inches	4 329x10⁻³	gallons
cubic inches	1 639x10⁻²	liters
cubic inches	0 03463	pints (liq.)
cubic inches	0 01732	quarts (liq.)
cubic yards	7 646x10⁵	cubic centimeters
cubic yards	27	cubic feet
cubic yards	46 656	cubic inches
cubic yards	0 7646	cubic meters
cubic yards	202 0	gallons
cubic yards	764 6	liters
cubic yards	1616	pints (liq.)
cubic yards	807 9	quarts (liq.)
cubic yards per minute	0 45	cubic feet per sec.
cubic yards per minute	3 367	gallons per second
cubic yards per minute	12 74	liters per second
degrees (angle)	60	minutes
degrees (angle)	0 01745	radians
degrees (angle)	3600	seconds
dynes	1 020x10⁻³	grams
dynes	7 233x10⁻⁵	poundals
dynes	2 248x10⁻⁶	pounds
ergs	9 486x10⁻¹¹	British thermal units
ergs	1	dyne-centimeters
ergs	7 376x10⁻⁸	foot-pounds
ergs	1 020x10⁻³	gram-centimeters
ergs	10⁻⁷	joules
ergs	2 390x10⁻¹¹	kilogram-calories
ergs	1 020x10⁻⁸	kilogram-meters
feet	30 48	centimeters
feet	12	inches
feet	0 3048	meters
feet	36	varas
feet	1/3	yards
feet of water	0 02950	atmospheres

METRIC CONVERSION TABLE (CONTINUED)

Multiply	by	to obtain
feet of water	0.8826	inches of mercury
feet of water	304.8	kgs. per sq. meter
feet of water	62.43	pounds per sq. ft.
feet of water	0.4335	pounds per sq. inch
foot-pounds	1.286×10^{-3}	British thermal units
foot-pounds	1.356×10^{7}	ergs
foot-pounds	5.050×10^{-7}	horse-power-hours
foot-pounds	1.356	joules
foot-pounds	3.241×10^{-4}	kilogram-calories
foot-pounds	0.1383	kilogram-meters
foot-pounds	3.766×10^{-7}	kilowatt-hours
foot-pounds per min	1.286×10^{-3}	B.t. units per minute
foot-pounds per min	0.01667	foot-pounds per sec
foot-pounds per min	3.030×10^{-5}	horse-power
foot-pounds per min	3.241×10^{-4}	kg.-calories per min.
foot-pounds per min	2.260×10^{-5}	kilowatts
foot-pounds per sec	7.717×10^{-2}	B.t. units per minute
foot-pounds per sec	1.818×10^{-3}	horse-power
foot-pounds per sec	1.945×10^{-2}	kg.-calories per min.
foot-pounds per sec	1.356×10^{-3}	kilowatts
gallons	8.345	pounds of water
gallons	3785	cubic centimeters
gallons	0.1337	cubic feet
gallons	231	cubic inches
gallons	3.785×10^{-3}	cubic meters
gallons	4.951×10^{-3}	cubic yards
gallons	3.785	liters
gallons	8	pints (liq.)
gallons	4	quarts (liq.)
gallons per minute	2.228×10^{-3}	cubic ft. per second
gallons per minute	0.06308	liters per second
grains (troy)	1	grains (av.)
grains (troy)	0.06480	grams
grains (troy)	0.04167	pennyweights (troy)
grams	980.7	dynes
grams	15.43	grains (troy)
grams	10^{-3}	kilograms
grams	10^{3}	milligrams
grams	0.03527	ounces
grams	0.03215	ounces (troy)
grams	0.07093	poundals
grams	2.205×10^{-3}	pounds
horse-power	42.44	B.t. units per min.
horse-power	33,000	foot-pounds per min.
horse-power	550	foot-pounds per sec.
horse-power	1.014	horse-power (metric)
horse-power	10.70	kg.-calories per min.
horse-power	0.7457	kilowatts
horse-power	745.7	watts
horse-power (boiler)	33,520	B.t.u. per hour
horse-power (boiler)	9.804	kilowatts
horse-power-hours	2547	British thermal units
horse-power-hours	1.98×10^{6}	foot-pounds
horse-power-hours	2.684×10^{6}	joules
horse-power-hours	641.7	kilogram-calories
horse-power-hours	2.737×10^{5}	kilogram-meters
horse-power-hours	0.7457	kilowatt-hours
inches	2.540	centimeters
inches	10^{3}	mils
inches	.03	varas
inches of mercury	0.03342	atmospheres
inches of mercury	1.133	feet of water
inches of mercury	345.3	kgs. per sq. meter
inches of mercury	70.73	pounds per sq. ft.
inches of mercury	0.4912	pounds per sq. in.
inches of water	0.002458	atmospheres
inches of water	0.07355	inches of mercury
inches of water	25.40	kgs. per sq. meter
inches of water	0.5781	ounces per sq. in.
inches of water	5.204	pounds per sq. ft.
inches of water	0.03613	pounds per sq. in.
kilograms	980.665	dynes
kilograms	10^{3}	grams
kilograms	70.93	poundals
kilograms	2.2046	pounds
kilograms	1.102×10^{-3}	tons (short)
kilogram-calories	3.968	British thermal units
kilogram-calories	3086	foot-pounds
kilogram-calories	1.558×10^{-3}	horse-power-hours
kilogram-calories	4183	joules
kilogram-calories	426.6	kilogram-meters
kilogram-calories	1.162×10^{-3}	kilowatt-hours
kg.-calories per min.	51.43	foot-pounds per sec.
kg.-calories per min.	0.09351	horse-power
kg.-calories per min.	0.06972	kilowatts
kilometers	10^{5}	centimeters
kilometers	3281	feet
kilometers	10^{3}	meters
kilometers	0.6214	miles
kilometers	1093.6	yards
kilowatts	56.92	B.t. units per min.
kilowatts	4.425×10^{4}	foot-pounds per min.
kilowatts	737.6	foot-pounds per sec.
kilowatts	1.341	horse-power
kilowatts	14.34	kg.-calories per min.
kilowatts	10^{3}	watts
kilowatt-hours	3415	British thermal units

Multiply	by	to obtain
kilowatt-hours	2.655×10^{6}	foot-pounds
kilowatt-hours	1.341	horse-power-hours
kilowatt-hours	3.6×10^{6}	joules
kilowatt-hours	860.5	kilogram-calories
kilowatt-hours	3.671×10^{5}	kilogram-meters
$\log N$	2.303	$\log_e N$ or $\ln N$
$\log_e N$ or $\ln N$	0.4343	$\log_{10} N$
meters	100	centimeters
meters	3.2808	feet
meters	39.37	inches
meters	10^{-3}	kilometers
meters	10^{3}	millimeters
meters	1.0936	yards
miles	1.609×10^{5}	centimeters
miles	5280	feet
miles	1.6093	kilometers
miles	1760	yards
miles	1900.8	varas
miles per hour	44.70	centimeters per sec.
miles per hour	88	feet per minute
miles per hour	1.467	feet per second
miles per hour	1.6093	kilometers per hour
miles per hour	0.8684	knots
miles per hour	26.82	meters per minute
miles per hour per sec.	44.70	cms. per sec. per sec.
miles per hour per sec.	1.467	ft. per sec. per sec.
miles per hour per sec.	1.6093	kms. per hr. per sec.
miles per hour per sec.	0.4470	M. per sec. per sec.
months	30.42	days
months	730	hours
months	43,800	minutes
months	2.628×10^{6}	seconds
ounces	8	drams
ounces	437.5	grains
ounces	28.35	grams
ounces	.0625	pounds
ounces per square inch	0.0625	pounds per sq. inch
pints (dry)	33.60	cubic inches
pints (liq.)	28.87	cubic inches
pounds	444.823	dynes
pounds	7000	grains
pounds	453.6	grams
pounds	16	ounces
pounds	32.17	poundals
pounds of water	0.01602	cubic feet
pounds of water	27.68	cubic inches
pounds of water	0.1198	gallons
pounds of water per min.	2.669×10^{-4}	cubic feet per sec.
pounds per cubic foot	0.01602	grams per cubic cm.
pounds per cubic foot	16.02	kgs. per cubic meter
pounds per cubic foot	5.787×10^{-4}	pounds per cubic in.
pounds per cubic foot	5.456×10^{-9}	pounds per mil foot
pounds per square foot	0.01602	feet of water
pounds per square foot	4.882	kgs. per sq. meter
pounds per square foot	6.944×10^{-3}	pounds per sq. inch
pounds per square inch	0.06804	atmospheres
pounds per square inch	2.307	feet of water
pounds per square inch	2.036	inches of mercury
pounds per square inch	703.1	kgs. per sq. meter
pounds per square inch	144	pounds per sq. foot
quarts	32	fluid ounces
quarts (dry)	67.20	cubic inches
quarts (liquid)	57.75	cubic inches
rods	16.5	feet
square centimeters	1.973×10^{5}	circular mils
square centimeters	1.076×10^{-3}	square feet
square centimeters	0.1550	square inches
square centimeters	10^{-4}	square meters
square centimeters	100	square millimeters
square feet	2.296×10^{-5}	acres
square feet	929.0	square centimeters
square feet	144	square inches
square feet	0.09290	square meters
square feet	3.587×10^{-8}	square miles
square feet	1296	square varas
square feet	1/9	square yards
square inches	1.273×10^{6}	circular mils
square inches	6.452	square centimeters
square inches	6.944×10^{-3}	square feet
square inches	10^{6}	square mils
square inches	645.2	square millimeters
square miles	640	acres
square miles	27.88×10^{6}	square feet
square miles	2.590	square kilometers
square miles	3,613,040.45	square varas
square miles	3.098×10^{6}	square yards
square yards	2.066×10^{-4}	acres
square yards	9	square feet
square yards	0.8361	square meters
square yards	3.228×10^{-7}	square miles
square yards	1.1664	square varas
temp. (degs. C.) + 17.8	1.8	temp. (degs. Fahr.)
temp. (degs. F.) − 32	5/9	temp. (degs. Cent.)
tons (long)	2240	pounds
tons (short)	2000	pounds
yards	9144	meters